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Abstract

The international climate mitigation regime, notably the Kyoto Protocol, has so far proven to be largely unsuccessful at slowing down the trend of increasing greenhouse gas emissions. Incomplete participation and the lack of any enforcing mechanism in IEAs are cited as the reason for the failure climate agreements like Kyoto. Coalition stability literature suggests the use of trade restrictions like border carbon adjustments complementary to climate policy with respect to their potential to generate greater cooperation and serve as enforcement of international environmental agreements. A variety of political, economic and legal reasons have so far prevented any meaningful use of border adjustments in conjunction with IEAs. Therefore, to assess the implications of border adjustments for participation and stability of climate coalitions, I develop a model of multilateral trade extended to climate concerns by way of domestic carbon prices and a border tariff adjustment levied on outsiders to the coalition. The model is solved analytically by allowing players to strategically optimize their carbon pricing decisions with and without the adjustment in a partial cooperation setting. Using the concept of internal and external stability, comparison between scenarios produces the result that a border tariff adjustment levied on imports unambiguously increases participation in the IEA as well as stability of larger coalitions. Further, the imposition of the border measure proves to be both credible and environmentally effective because it increases the welfare of the coalition and the world as a whole as well as reduces emissions by depressing output.

Table of Contents

1. Introduction

Anthropogenic climate change is gathering speed and environmental problems caused by increasing emissions of greenhouse gases (GHGs) have become more threatening in recent years. This evidence for this statement can be seen most recently in IPCC's Fifth Assessment Report (2014) which details the impact of man-made increases in global temperatures (global warming) and its subsequent impact on the economy and environmental. The report highlights the importance a global commitment to mitigate climate change by way of inducing and increasing international cooperation on the issue. Why is international cooperation necessary? Increasing GHG emissions pose a common worldwide problem because of their trans-boundary nature. That is, the environmental problems caused by increasing concentrations of GHGs in the atmosphere are not localized but instead have a global impact, irrespective of international boundaries.

The negative externality of emissions increase is global but so is the positive externality of a reduction in emissions. This is because a benefit from a decrease in environmental damage from reduced emissions is a public good i.e. it is non-excludable (as well as non-rival meaning that the benefit may be enjoyed by all players without a reduction in benefit of any player). The public good character of climate mitigation leads to the problem of 'free-riding' whereby a country obtains the benefit of lower environmental damage due to other countries' mitigation efforts either by not being party to an international climate agreement or contributing less to mitigation efforts. Therefore, unless mitigation efforts are cooperative on an international scale, individual players will not bear the economic and political cost of emission abatement.

The landscape of international climate cooperation has been dominated in recent years by the Kyoto Protocol – a multilateral agreement extending the 1992 United Nations Framework Convention on Climate Cooperation (UNFCCC). While the protocol has achieved its collective mitigation target, its environmental effectiveness has been called into question. Much of the emission reduction is attributed to factors others than the Kyoto Protocol like economic downturns in major emitting nations (Stavins et al., 2014). Responsible for the limited effectiveness of the Kyoto agreement is the fact that participation is incomplete and likely to decrease in forthcoming years and commitments to reduce emissions are not mandatory as per the agreement. The largest emitter, USA has not ratified the Kyoto Protocol while others like Canada, Japan, Russia etc., have either withdrawn from the agreement or opted out of the second commitment period (2013-2020).
Even if the mitigation pledges in the Copenhagen-Cancún regime and the abatement targets in the second commitment period of Kyoto Protocol are fully implemented and successful, they will be inadequate to achieve the long-term goal of limiting global temperature increase to 2℃ above pre-industrial levels. However, a well-defined and effective climate regime seems unlikely in the near future. Little progress has been made to construct a global climate change policy addressing emission reduction and pursuit of clean technologies, especially in the wake of inconclusive negotiations at UNFCCC's COP 19 and no concrete agreement post-Kyoto.

The current situation of partial cooperation has led to abatement commitments being pursued unilaterally by some countries most notably the EU (see also Helm et al., 2012, pp. 373) while comparable efforts to reduce emissions in the developing world remain mainly absent. This gives rise to asymmetries in carbon pricing between countries. In a world where the production and consumption of carbon-heavy goods is highly integrated via international trade, these differences in carbon costs affect the competitiveness of firms as well as induce carbon leakage. Carbon leakage renders national climate policies ineffective because it only implies a shift in the location of emissions and not a genuine reduction. International trade has been identified as one of the major drivers of leakage (Droege, 2011). Consequently, the implementation of trade restrictions like border carbon adjustments has been proposed as an option to counter leakage and loss of competitiveness of domestic firms borne out of unilateral climate policing. There has been, however, no unequivocal evidence of the ability of border measures to significantly reduce leakage or protect domestic production. Further, unilateral trade restrictions designed explicitly to protect domestic industries are likely to invite retaliation and fuel the possibility of trade conflicts (Barrett, 2011).

However, the solution to avoiding political and trade conflicts is not to limit the use of trade restrictions. Authors like Barrett (2003, 2011), Stiglitz (2007) and Victor (2011, cited in Stavins et al., 2014) suggest that trade restrictions have a role to play in addressing the issue of climate change as well. International trade and climate policy are inextricably linked. On one hand, globalization of trade influences carbon flows and on the other hand differentiated climate change policies change the relative prices of goods and services affecting trade flows and the volume of traded goods. While these may be the driving forces behind carbon leakage and competitiveness loss, the rationale for using border carbon adjustments goes beyond these concerns. It seems obvious that the overarching goal should be to target the cause of the problem. That is, restructuring climate and international trade regimes such that such that they complement instead of threaten each other. The authors, therefore, propose the use of trade restrictions as a tool to increase and enforce participation in international environmental agreements (IEAs). Greater participation in IEAs, all else equal, will improve the efficiency of such agreements by accounting for a larger portion of GHG emissions thereby increasing global welfare (Stavins et al., 2014). Further, if the restrictions were to succeed in creating larger IEAs, they would inadvertently have the economic impact of reducing carbon leakage.

So far, trade restrictions in climate policy have been used as an aid to domestic carbon-pricing policies but they their use as a strategic tool to affect cooperation in climate agreements has been overlooked. This is despite game theoretic research that shows restrictive trade measures can encourage participation in environmental treaties (see Section 4). There is also ample evidence from various international agreements that have successfully employed trade sanctions in the past, for example, the Fur Seal Treaty of 1911 and the Montreal Protocol of 1987. The objective of trade restrictions in these agreements has been to encourage participation and enforce the agreement (Barrett, 2011).

Given this background, the aim of this paper is to contribute to the discussion of how trade measures may be used to encourage cooperation in a climate agreement via strategic carbon tariff interactions of the players which optimize their benefits. I use a game theoretic approach to determine the impact of border carbon adjustments, a form of trade restriction, on participation and stability in IEAs. To this end, I develop an n-country trade model extended by climate concerns in the form of domestic carbon tariffs and an environmental damage function arising out of emissions from production. The model is inspired from Eyland and Zaccour's (2012) model of strategic tariff interaction. A trade restriction, i.e., a positive border tariff adjustment, available only to signatories of the IEA, is then applied to the partial cooperation scenario to investigate its effect on coalition size and stability in equilibrium.

Formally,

Can border carbon adjustments increase participation in IEAs? Put differently, does the imposition of a positive border adjustment increase the stability of a given coalition size?

There are, however, reservations about using trade sanctions for various reasons. Since trade is multilateral, trade sanctions may not only have an adverse impact on the violator but also on the country levying it. That is, the threat of imposing border carbon adjustments will only be considered ‘credible’ if the states imposing it are better off with them than without[1]. Further, as I explain in subsequent sections, border adjustments in trade may not be compatible with international trade laws of non-discrimination as well as for political issues concerning climate mitigation. To be granted an exception, however, it may be possible to show, with a compatible adjustment-design and analytical models like these, that the underlying motive of combining trade policy with climate concerns is to reduce global GHG emissions and thereby increase global welfare. Increasing cooperation in IEAs by using border carbon adjustments may be shown as a desirable avenue of doing so but it must then be accompanied by the proof that it will achieve this objective. It is, therefore, also important to test whether the border carbon adjustment on imports, as modeled in this paper, passes the test of credibility and environmental effectiveness in terms of global welfare and emissions. I ask the following question,

What is the impact of a positive border adjustment on welfare and output of the players involved as well as of the world as a whole?

The rest of the paper is structured as follows. Section 2 describes the various rationales and motivations behind the propositions to use border carbon adjustments. Section 3 lays out the various political, legal and design challenges facing border measures as well as enumerates some practical recommendations and designs for their implementation. In section 4, I review the game theoretic literature on coalition formation as well as literature on border carbon adjustments. Section 5 introduces the model framework and the environmental agreement setup. Section 6 presents the n-country generalization and characterizes the equilibrium strategies under three scenarios: no cooperation, full cooperation and partial cooperation. Section 7 compares the degree of participation and stability of IEAs in the presence of border carbon adjustments with those in their absence. Section 8 determines the impact of a border adjustment on welfare and output. Section 9 concludes.

[1] I determine, as an aside, whether a border carbon adjustment as modeled in this paper is pareto-improving in terms of welfare for all players involved which may make the imposition of the adjustment more palatable to the players facing it.

2. The Theory of Border Carbon Adjustments

According to classical trade theory, for trade to be mutually beneficial, relative production costs of all trading partners should be different. Now, differentiated costs may arise from either differences in utility or even the differentiated impact of negative externalities that result from production of the traded good. An example of this is the environmental pollution that results from the emissions of GHGs. When the environmental impact of production is a secondary concern of developing economies, they gain a comparative advantage by specializing in the production of these 'dirty' goods, especially if the factors of production, such as labor and carbon-heavy fuels like coal are cheap.

Further, the classical trade theory assumes that gains from trade can offset the impact of negative externalities only if factors of production are appropriately priced. That is, for example, if the difference in the negative externality arising from use of fossil fuels like coal and crude oil versus renewable energy is properly priced, say using a global carbon price. In fact it is due to the presence of such externalities and the failure to internalize them that free trade may reduce global welfare (Helm et al., 2012). However, carbon pricing in reality is highly differentiated and in some cases even absent. For these reasons, restricting trade based on how a good is *produced* would contradict the basic tenets of trade theory, for e.g., a unilateral climate policy that puts tighter carbon constraints on domestic producers compared to foreign producers.

Currently, the UNFCCC applies the polluter-pays principle when designing national climate mitigation policies. Under this principle, GHG emissions are accounted for at the point of production termed production-based accounting (PBA) and consequently climate protection policies are aimed at producers of the goods. In other words, emissions are tracked only in the producing country irrespective of by whom or where the goods are consumed after that. An alternative approach to track emissions is accounting for GHG emissions based on where the goods are consumed irrespective of where they are produced. Using this consumption-based accounting (CBA) principle all imports of a country will be part of the GHG emissions inventory and all exports would not (Peters et al, 2011).

Even though both accounting principles cover global emissions, investigation of global carbon trade flows yield national differences in the carbon produced and carbon consumed. This so-called 'net carbon trade balance' is determined by analyzing current global trade flows while accounting for the embedded carbon content in the goods and services. Developed or industrialized nations tend to be net importers of embedded carbon while developing nations tend to be net exporters (Peters and Hertwich, 2008a, b). Similar conclusions are reached in other literature analyzing international carbon trade flows. Subsequent studies have shown an increase in consumption-based emissions as well as a widening gap between the production and consumption of carbon in developed and developing countries (Droege, 2011; Weidmann et al., 2008 cited in Helm et al., 2012). Droege (2011) and Helm et al. (2012) note that national carbon production and consumption differentials do not necessarily increase pollution and instead reflect the existing trade patterns between different regions. However, the future of these trade flows depends on the climate mitigation policies adopted by each trade partner and the impact on pollution by differing policies. International trade, therefore, interacts with climate policy on different levels.

There is growing literature advocating international climate mitigation policies based on CBA. That is, pricing consumption of carbon in order to counter the impact of increasing carbon-heavy imports by developed countries on GHG emissions (Droege, 2011; Peters and Hertwich, 2008 a, b). According to the authors, a case could be made for using CBA if the PBA system of current unilateral carbon policies causes undesirable shifts in carbon flows.

Unilateral carbon constraints and the existence of carbon price differentials may indeed lead to increase in GHG emissions if their production is simply shifted to less carbon-regulated markets. This phenomenon is described as ‘carbon leakage’, which may be defined as the ratio of increase in GHG emissions from a specific sector in carbon-unregulated regions due to emission reduction policies undertaken by the abating countries affecting that sector (Reinaud, 2008). Further, Droege (2011) enumerates two leakage concepts. The ‘consumption-induced carbon leakage’ concept encompasses the emissions embodied in the goods imported by a country from another following the scenario where only one of the two trade partners involved is bound by carbon-constraining measures. This leakage is exacerbated by increasing carbon production-consumption differentials. The second leakage concept termed as ‘policy-induced carbon leakage’ is caused by the increase in emissions in carbon-unregulated regions due to the mitigation policy adopted by abating region. Therefore, the leakage caused by the implementation of unilateral mitigation policies would add to the existing leakage caused by consumption of imports.

According to Droege et al. (2009), policy-induced leakage can be traced back to two interconnected channels. Leakage occurs when industries face higher costs in abating countries, leading to the diversion of production of carbon-heavy goods to less regulated regions with lower per unit cost. This in turn causes loss in competitiveness and employment in the abating regions. This type of leakage can be the result of one or a combination of three phenomena - multinational firms choosing to reduce domestic production and increase production abroad in less regulated countries, firms choosing to set up new production facilities abroad or firms choosing to cease domestic production and shift the entire production abroad. These phenomena seem to be more prevalent in emissions-intensive and trade exposed (EITE) sectors. Leakage may also be triggered via the fossil-fuel price channel. When carbon-constrained countries reduce consumption of fossil fuels, international energy prices fall thereby increasing demand and consequently emissions in less regulated regions.

The question follows, how much leakage is attributed to international differences in carbon pricing? The evidence of leakage differs with ex ante and ex post studies. Ex ante studies rely on data from a single year to estimate potential carbon leakage rates in the future. The estimates vary widely with different studies depending on different assumptions about market behaviors of energy-intensive industries, elasticity of demand, a sector’s trade exposure, emission intensity, product substitutability, supply elasticity of fossil fuels, etc. (Monjon and Quirion, 2011; IPCC, 2007; Tamiotti, 2011; Zhang 2012). A survey of various ex ante studies predicting leakage rates post-Kyoto by the IPCC Fourth Assessment Report (Barker et al., 2007) suggests that leakage estimates after the Kyoto Protocol was implemented generally range from ‘5-20% as a result of loss in price competitiveness…’. These leakage rates are in line with the estimates from other surveys, 2-21% in Gerlagh and Kuik (2007, cited in Zhang, 2012) and 5-25% in Droege (2009).

The aforementioned leakage rates are estimated at an economy-wide aggregated level and may not accurately reflect the leakage associated with the most carbon-heavy goods. This is because energy-intensive industries such as steel, cement and aluminium are the biggest emitters of GHGs and therefore relative emission intensities of foreign goods as well as elasticities of substitution for these narrowly defined subsectors are higher compared to aggregate values belying higher levels of leakage (Fischer and Fox, 2012). Further, energy-intensive industries are at a greater risk of leakage because their goods account for a large portion of international trade traffic as well as operate with some degree of product and process uniformity so that consumer indifference between them is larger than other goods (Zhang, 2012). Therefore, calculating leakage effects at the sectoral level may be more appropriate (Monjon and Quirion, 2011). In recent literature, the EU Emissions Trading Scheme (ETS) has been the focus of sector-specific studies in order to determine the impact of unilateral climate policies on EITE industries. Zhang (2012) reviews the example of iron and steel industries citing various studies (see Zhang, 2012, pp. 237) which show that partial equilibrium analysis for these sectors reveal greater leakage than suggested by aggregate models. The cement industry is particularly vulnerable; Ponssard and Walker (2008) find that in this sector the EU ETS is likely to induce high levels of carbon leakage through increased imports and production diversion (see also Droege, 2011, pp. 1192 and Helm et al., 2012, pp 377).

Ex post studies, on the other hand, use historical data. Recent implementations of environmental tax reforms and GHG emission trading schemes in the EU provide a basis for ex post studies of observed leakage. Based on available data, studies neither show evidence of carbon leakage and competitiveness loss in EITE industries nor of undesirable shifts in trade flows (Reinaud, 2008). However, the insights from ex post analyses on leakage and competitiveness are of limited value given the short time since the implementation of the EU ETS and that most energy-intensive industries were not covered in the first phase of the scheme (2005-2007). The short timespan does not allow a study of the full potential impact of the carbon restrictions, especially in view of the fact that abatement targets are set to become more ambitious along with an increase in the auctioning of permits. That is, emission trading is expected to become a stricter regime and therefore existing carbon price differentials are expected to increase (Helm et al., 2012). Contradictory estimates on leakage by ex ante and ex post studies, therefore, provide insufficient evidence that industries in abating regions will not face the risk of leakage and loss in comparative advantage in the future.

Given the continuing leakage and competitiveness concerns, adoption of ambitious domestic emission reduction targets has been vigorously contested by industrial and political lobbies. In the EU, particularly in the aftermath of the EU ETS, to politically stabilize industrial factions, competitiveness concerns have been addressed by giving free emission allowances to the EITE industries This in effect constitutes an implicit subsidy to dirty production. Further, the policy of ‘grandfathering of emission permits has increased the scale of lobbying for exemption and special subsidies. This leads to more trade inefficiencies and creates perverse incentives at the margin for increasing emissions (Hepburn, 2006).

It can be concluded that, given the current scenario of unilateral policing, free trade may not necessarily increase welfare due persisting global differentials in carbon pricing that induce trade diversion. In other words, the issues of policy-induced leakage and loss of competitiveness can be traced back to the role international trade plays in the location and shift of GHG emissions. Furthermore, literature on strategic environmental policy in the presence of trade suggests that free trade can be detrimental to incentives to price carbon correctly in the presence of unilateral carbon policies (Baksi, 2014; Baksi and Ray Chaudhuri, 2009). That is, without international cooperation countries may reduce domestic firms' carbon costs to increase competitiveness thereby rendering their climate policy inefficient. What is the solution?

A redesign of trade policy could potentially be used to limit leakage and loss of competitiveness, but more importantly, avoid the debilitating effects of weakening environmental regulation due to insufficient international cooperation. According to Droege (2011) trade measures can complement climate policies and make them more efficient by preventing domestic carbon pricing being circumvented by importing substitutes. Trade measures may also discourage the diversion of production activities to less regulated regions and the subsequent re-importation of the goods. The redesign can come in the form of border carbon adjustments that serve as a means to extend national carbon pricing schemes to internationally traded goods.

There are four ways of motivating the use of border adjustments, a form of trade sanction, in climate policy. Firstly, border levelling measures that impose an indirect carbon price on less regulated regions, say by increasing the import price in the abating regions, would theoretically lead to an increase in global welfare (Gros and Egenhofer, 2011). The increase in welfare would result from larger internalization of the negative externality of GHG pollution via a reduction in carbon price differentials and the associated smaller trade flows. Secondly, border measures could level the playing field and ensure competitiveness for producers in the emissions-heavy and fossil fuel-reliant sectors in countries with existing unilateral policies (Carbon Trust, 2010; Droege et al., 2009). Thirdly, apart from leakage concerns, border carbon adjustments may also be viewed as putting a price on consumption of carbon instead of production of carbon. In other words, the issue of border adjustments can also be broached from the production versus consumption-based accounting perspective. A border adjustment that extends a domestic carbon price (an ETS or a tax) to all carbon-heavy goods produced in unregulated regions that are consumed domestically, would create a national carbon policy that addresses consumption (Droege, 2011). Such border measures, therefore, embody the shift from production-based accounting to consumption-based accounting. Lastly, and perhaps most importantly, in game theoretic literature, trade restrictions have been shown to provide leverage to induce international cooperation in environmental agreements (see Section 4 for examples of literature).

The lack of harmonized global carbon pricing is likely to prevail in the near future as evidenced by inconclusive international negotiations regarding coordinated action in COP 19. International efforts to abate emissions will, therefore, rely mainly on unilateral carbon policies, at least until 2020. That is, all national emission abatement targets will be designed according to national jurisdictions. National pledges, even if they follow a common approach, are likely to have significantly varying carbon prices and be limited in scope and complexity. Further, unilateral climate policies currently employing production-based accounting of emissions have been shown to create inefficiencies such as carbon leakage and loss in competitiveness. Consequently, when analyzing the potential of trade measures like border carbon adjustments to support climate mitigation policies, it is important to discuss the political, legal and institutional design issues involved with the implementation of border measures as well as the environmental implications of the shift.

The subsequent section is divided into two parts. First, I detail the political and legal challenges faced by border carbon adjustments. Secondly, in view of the design challenges faced by border carbon adjustments, I summarize some institutional design options and practical recommendations for their implementation.

3. Political, Legal and Design Challenges for Border Measures

3.1 The Struggle for Compatibility

The objective of border carbon measures is to reduce international carbon-pricing differentials by extending a domestic climate mitigation scheme to traded products. A border adjustment may take the form a border tariff adjustment (BTA) either as tax on imports (to level the domestic consumption playing field) or rebates to exports to non-abating regions (to level the field for producers). Further, a BTA may also be 'fully-adjusted' i.e. a BTA that includes import tax and export rebates (Boehringer et al., 2012; Fischer and Fox, 2012). Border measures may also take the form of surrender of emission allowances by importers of goods from less carbon constrained regions.

The idea of border carbon adjustments has been around for a while; foundational variations of it have cropped up in the Waxman/Markey Bill (American Clean Energy and Security Act of 2009) where importers were required to purchase 'international reserve allowances', the Bingaman/Specter Bill (Low Carbon Economy Act) requiring importers to buy emission permits and the Lieberman/Warner Bill directing importers to buy Certified Emission Reduction (CERs) (Veel, 2009). In the EU ETS as well, the inclusion of imports has been presented as an option. To give an example, the recent inclusion of aviation in the EU ETS mimics a *de facto* border adjustment as all countries are required to purchase emission allowances for all flights arriving or departing in the EU. This measure, however, has been a highly contentious issue among several countries.

The crux of the political and legal debate surrounding the implementation of border measures is that international climate mitigation policies and global trade policies are based on different fundamental principles. Therefore, any policy measure interlinking the two must take into consideration the existing climate change framework under UNFCCC and the international trade framework under the WTO and that they may not be compatible with each other.

Climate policy under the UNFCCC is guided by the principle of 'common but differentiated responsibilities' (CBDR) specifying how the burden of reducing greenhouse gas emissions should be distributed between countries. According to this principle, the responsibility of any one country to reduce GHG emissions can be judged in line with its historic emissions and current capacity to undertake mitigation (UNFCCC, 1992) which created two different groups of countries: Annex I and Non-Annex I. It is important to note, however, that the CBDR principle does not provide guidance on which policy measures should be used to achieve reduced emissions. Further, it does not state how the cost of climate mitigation should be calculated or how it should be shared among countries.

As mentioned earlier, border carbon adjustments may be motivated by their ability to increase participation in IEAs, reduce loss in competitiveness of EITE industries by levelling the playing field for domestic and foreign producers as well as increase welfare by reducing global emissions. Involving more countries into an international agreement promotes 'common responsibility' with respect to mitigation. It is however, difficult to separate the three motivations during political debates on implementation of border measures, especially during arguments of 'fairness by differentiated responsibility'.

To make sense of the fairness debate, one needs to understand the objective of any border measure. Even though, adjustments based explicitly on the country of origin are in theory compatible with UNFCCC, any effort by border measures to level international cost playing fields counters the CBDR principle as the very intention of the principle is to induce different levels of competitiveness. Moreover, origin-based border carbon adjustments are accompanied by the inevitable political backlash from developing economies accusing industrialized countries of using border measures for 'green protectionism' i.e. increasing their comparative advantage instead of focusing on mitigation efforts (Droege, 2011; Gros and Egenhofer, 2011). Further, such trade measures are perceived as a way of providing abating countries with strategic leverage to coerce 'outsiders' to an environmental agreement to cooperate (Fischer and Fox, 2012). Especially, since most traded goods are produced using energy sources like coal and other fossil fuels, trade sanctions like border tariffs may undermine the subtle coercion by potentially fuelling trade wars (Boehringer et al., 2012; Fischer and Fox, 2012; Stavins et al., 2014). In Droege's (2011) words it is important, therefore, to weigh the risks of short-term political trade retaliation and long-term equity issues against the (uncertain) benefits of cross-border carbon pricing measures.

There is also a legal dimension to the border carbon adjustment debate centered on the free-trade laws under the WTO. The laws of the WTO establish the principle of non-discrimination: the Most Favoured Nation Treatment prohibits a country from discriminating between domestic and foreign producers based on their policies while the National Treatment Principle prohibits discrimination between foreign and domestic 'like' products (Veel, 2009). Since these adjustment measures seek to link climate policy with trade policy, the important issue for WTO members is whether these sanctioning policies are consistent with the non-discrimination principles; they may not be according to some legal research done on the issue (Droege, 2011; Stavins et al., 2014).

Several authors like Veel (2009), Tamiotti (2011) and Zhang (2012) etc., describe the various provisions and restrictions of trade laws that can influence the framework design of a border adjustment. According to the authors, while the General Agreement on Tariffs and Trade (GATT) under WTO may place certain restrictions on the structural format of a carbon tariff applicable at the border, such tariffs may not be categorically prohibited under WTO. The non-discrimination principles may be suspended in cases where exceptions to the free-trade laws can be determined. Article XX of GATT may provide such an exception. According to this article, a case could be made for granting an exception to a discriminatory border measure if it is purposed for the conservation of some exhaustible natural resource – in this case the global environment. There are however, a number of legal conditions to be met. The chapeau of Article XX requires that the border measure may not constitute "arbitrary or unjustifiable discrimination between countries where the same conditions prevail" or a "disguised restriction on international trade" (Veel, 2009). That is, the main objective of the border measure should be to achieve its environmental goal and may not be purposed to protect domestic production or coerce cooperation.

Moreover, by definition the CBDR and the non-discrimination principle of the WTO are not compatible with one another. Any and all border measures need to be WTO-compliant. However, to be granted an exception under Article XX of GATT the objective of the measures needs to be ecological effectiveness, for example, to reduce carbon leakage and overall emissions (Cosbey et al., 2012; Droege, 2011; Zhang, 2012). In other words, the trade measure will not be provided exception if it is pursued as a sanction for a country that has not joined an environmental agreement or to ensure domestic competitiveness. They may only be levied if, even after sufficient efforts to engage emitters in climate mitigation efforts, comparable efforts have not been undertaken to reduce emissions. The problem lies, as mentioned above, in detangling the underlying motive of the border measure as they are interlinked. If the marriage of a climate and trade policy is construed as having protectionist or eco-imperialist agendas that undermine the CBDR principle, implementation of border carbon adjustments becomes a contentious political issue.

According to some research (Monjon and Quirion, 2011; Tamiotti, 2011), it is possible, in theory, to construct border carbon adjustments that are compatible with WTO laws. It may be argued that with some particular design, the fundamental objective of the border measure is only environmental. Put succinctly, adjustments based only on emissions associated with the traded goods, applied to imports or exports and linked to the prevailing domestic carbon pricing policy may be potentially more favored by the WTO. However, political challenges might still remain; arguments for exceptions under GATT are not guaranteed acceptance and closely hinge on proving ecological efficiency of a particular border measure design (Fischer and Fox, 2012). The legality issue can be summarized by saying that although a WTO dispute panel can rule on a specific design, the rules cannot make clear if border carbon adjustments are in general WTO-compliant as there is no existing precedent (Helm et al., 2012).

3.2 Design and Practical Implementation

When implementing a trade sanction like a border measure, the political, legal and practical design dimensions need to be kept in mind. Various studies (Boehringer et al., 2012; Cosbey et al., 2012; Droege, 2011; Gros and Egenhofer, 2011; Helm et al., 2012; Fischer and Fox, 2012; Monjon and Quirion, 2010) recommend some common policy directives that must to be adhered to while proposing border carbon adjustments - :

- Of all the motivations for applying a border adjustment, reducing the underlying GHG emissions i.e. ecological effectiveness should be the only one to be explicitly modeled.

- BCAs must be used complementary to domestic price-based policies and not as a stand-alone measure.

- Importers levied with a border adjustment must face the same payment method as domestic producers. Further, the effective carbon price faced by importers on 'like' domestic products must be less than or equal to the carbon price faced by the domestic producers so that no group is less favored.

- Other countries' climate mitigation policies must be assessed based on a formal judgment involving all players. There must also be provisions to allow the exporting countries affected by the border measure to appeal the judgment or implement changes to their carbon-pricing policy before the border measure is in place.

- While negotiating the size of a border adjustment, partial exemption should be given to countries making comparable mitigation efforts. Compensation or credit schemes may also be provided to importers to account for price-based carbon policies employed by the exporting region.

- Border carbon adjustments should be intended as temporary policy measure during the transition of countries from high to low carbon economies.

The various studies mentioned above also go on to suggest possible designs and practical implementations of border adjustments. Some main features need to be identified and agreed upon while designing effective and WTO-compliant border carbon adjustments. These include the type of border adjustment (it may constitute an import tariff or an export rebate, or even a full border adjustment that combines import tariffs and export rebates), payment options, calculation of embedded carbon, the products and industrial sectors covered, etc. (Monjon and Quirion, 2010).

As mentioned before, any import adjustment is required to treat 'like' domestic and imported products on an equally fair basis and may not discriminate among trading partners. However, even if the border import tariff is ruled to be discriminatory, an exception could be sought under Article XX of GATT as explained earlier. Policymakers may also choose to rebate exports at the border whereby exporters from carbon regulated countries are recompensed and/or relieved of their domestic carbon payments when exporting to less regulated regions. This levels the playing field for domestic and international producers and may even reduce leakage by avoiding loss of market share in foreign markets (Boehringer et al., 2012). Export rebates, however, are not entirely WTO-compatible as they may be construed as a subsidy under the WTO's Agreement on Subsidies and Countervailing Measures. Further, according to Cosbey et al. (2012), export rebates are only compatible with no exemptions for exporting countries. In the real world, but, with likely exemptions and asymmetric carbon policies, export rebates at the border would constitute an unfair subsidy. More importantly, a rebate must not undo the incentives of a carbon price; due to multiple emission-intensity benchmarks in domestic regulation in a country, rebates may provide perverse incentives to prefer emission-heavy production or increase transport related emissions. To correct this, rebates may be based on sector-wide emission rather than firm-level emission intensities. At present however, WTO laws remain unclear on the inclusion of specific taxes on GHG emissions like export rebates adjustable at the border (Cosbey et al., 2012; Fischer and Fox, 2012).

Some authors (Boehringer et al., 2012; Cosbey et al., 2012; Droege, 2011; Gros and Egenhofer, 2011) suggest that the revenues from import tariffs may be directed back to the exporting country to reduce the potentially adverse redistributive efforts of border carbon adjustments on developing countries and possibly alleviate income inequalities. This re-direction of tariff revenues to developing regions also serves as means of addressing the 'capability' and 'responsibility' aspects of the CBDR principle. The revenues may also be used to finance international transfer funds under the umbrella of environmental agreements to help developing economies participate and/or comply with climate negotiations.

A border adjustment may either take the form of voluntary purchase/surrender of emission allowances or a carbon tariff. If importers are required to surrender allowances then it is suggested that it must be accompanied by the complete auction of emission permits and thus phase out ‘grandfathering’. This is due to the fact that free allocation of permits in the presence of border adjustments may appear to be an unfair subsidy to domestic producers.

There also exist technical problems associated with switching to a consumption-based accounting system like using border adjustments to correct for international carbon-pricing differentials. An appropriate level of border adjustment requires calculating the amount of carbon ‘embedded’ in internationally traded goods i.e. the amount of GHG emissions associated with the production of those goods. All goods, therefore, must be registered with their embedded carbon content. This raises two problems. Firstly, information about sectoral or firm-specific emission intensity is not available for all traded goods. Secondly, even if such information is available, there are no measuring or monitoring standards in place to ensure transparency and accountability. Further, there is difficulty associated with determining a fair adjustment price if imported products are subject to other climate regulations in their origin country, say compulsory investment in clean technology. This imposes a carbon cost that is difficult to internalize in border adjustments.

Calculating embedded emissions is difficult but not impossible. Given the logistical difficulties in assessing the true amount of embedded GHG emissions, alternative approaches may be used to define emission intensity. The key to designing border payments is ensuring that payments for embodied emissions in imports do not exceed payments for ‘like’ domestic products. To this end, benchmarking of emissions standards (product-specific or even process-specific) using domestic averages, sectoral averages or the average of the best available technology (BAT) may be used (Boehringer et al., 2012; Cosbey et al., 2012; Ismer and Neuhoff, 2007 cited in Droege, 2011). The application of an international emission standard agreed upon by trade partners reduces the scope for any real or perceived discrimination. Adjustments based on such a standardized assumption are likely to be allowed but may correspond to weak and less effective carbon pricing as it does not take into account the actual GHG emissions from all sources. Indeed, from an economic perspective it makes sense to discriminate against carbon-heavy imports but any kind of differentiated border adjustment would require special exemption under GATT (Fischer and Fox, 2012).

With respect to coverage, to balance the legal and administrative problems of implementation, border measures should offer narrow coverage. Only goods with high GHG intensity *and* high trade intensity should be covered. Further, border carbon adjustments should evolve through a sector-specific regime (Cosbey et al., 2012; Helm et al., 2012; Zhang, 2012). This implies starting with a specific carbon-heavy sector of basic end-use product like aviation or cement and gradually extending the adjustment to other EITE industries that are considered most vulnerable to leakage and competitiveness loss.
With respect to boundaries on estimation, only direct emissions including process emissions and indirect emissions i.e. those generated by electricity, heat, etc. off-site should be considered.

Summarily, it can be said that the design challenges and technical problems associated with the implementation of border carbon adjustments can be addressed in a pragmatic fashion. Even though border measures require a thorough comparison of the climate change policies of the countries involved, a reliable determination of covered products as well as methods of calculating embedded emissions, these features can be part of a well-designed adjustment.

The desirability of any particular design depends on relative emissions, size of consumption, specific sectors and countries considered, etc. Droege (2011) points out that for policy-making, the actual implementation of border measures is more of a political than a technical or design issue. A WTO-complaint border measure can be designed. However, proof of a non-protectionist agenda as well as the issue of who has more responsibility of mitigation may prove to be major obstacles to their implementation. Branger and Quirion (2014) predict, based on real world observations, that given the political and judicial complexities of implementing such measures, only a simplified version of border adjustments comprising of import tariffs, based on BAT benchmarks is likely to be forwarded.

4. Literature

An international climate mitigation policy may be designed to achieve depth i.e. ambition of emission reduction targets, and/or breadth i.e. participation. The debate on the design issue is – which motivation should take precedence? Emphasis on breadth of participation would allow for long-term progress towards reducing aggregate global emissions by promoting low-cost abatement techniques as well as developing international regulatory frameworks to facilitate compliance (Barrett, 2003). On the other hand, pursuing depth in mitigation can be motivated by the urgency of climate action that is required (IPCC, 2014). Studies, however, confirm that that the size of an IEA directly impacts the amount of leakage and loss in competitiveness; a larger IEA corresponds to lower leakage and vice versa (Boehringer et al., 2012; Branger and Quirion, 2014; Carbone et al., 2009). Pursuing ambitious mitigation targets, thus, may induce more not less leakage and may even make it difficult to increase participation in the future.

Since the early papers by Barrett (1994), Carraro and Siniscalco (1993), Chander and Tulkens (1992), Hoel (1992) etc., increasing attention has been given to game theory as a means to analyze international cooperation on environmental agreements. Game theory mirrors the real world by incorporating the strategic interactions between players and makes predictions based on those interactions. It, therefore, serves as an ideal tool for studying coalition games conferring a non-excludable positive externality to outsiders (Finus, 2008). Subsequent non-cooperative game-theoretic research on climate cooperation (Barrett, 2003, 2007; Carbone et al., 2009; Finus, 2001, 2003; Rubio and Ulph, 2007, to name a few) analyzes the incentives of players to join an IEA, measures to improve participation, stability and compliance as well as suggests design options.

Coalition formation is a two-stage process where in the first stage countries take membership decisions and in the second stage decide on the size of abatement. A coalition formation game can have several iterations depending on the assumptions implicit in the two-stage process and therefore different outcomes. Finus (2003) describes the standard assumptions in the basic game of coalition formation: open membership, single coalition, payoff functions comprising of only benefits from emissions and damage costs, Nash-Cournot welfare maximization where the coalition maximizes its aggregate welfare and singletons maximize individual welfare. A significant portion of game theoretic research on coalition formation using these standard assumptions studies the issue of participation in IEAs (Carraro and Siniscalco, 1993; Finus, 2001; Hoel, 1992). Even with some modifications to the basic assumptions for example, Stackelberg instead of Nash-Cournot equilibrium (Diamantoudi and Sartzetakis, 2006, Rubio and Ulph, 2006 cited in Eichner and Pethig, 2013a), these studies are quite pessimistic about large IEAs being stable.

Finus (2008) gives an overview of the design options with which the basic coalition formation model can be extended and modified. Successive studies use these extensions and modifications in an incremental fashion to analyze the impact on IEA participation and stability. These include studies analyzing a shift to exclusive membership (Eyckmans and Finus, 2006a; Finus, 2008; Finus and Rundshagen, 2009) which find that exclusivity to accession may help stabilize IEAs and prevent defection. Studies on the degree of consensus in accession to an IEA (Bloch, 2003; Eyckmans and Finus, 2006b; Finus and Rundshagen, 2009; Yi, 2003) show that a higher degree of consensus is conducive to more cooperation and stability in coalitions. Inclusion of international transfers, which may be monetary or technical, can also induce more participation and improve stability in IEAs by balancing real-world asymmetries in incentive structures and payoffs from cooperation (Eyckmans and Finus, 2006b; Finus, 2003, 2008). Linkages between issues may also help to increase participation in IEAs. Climate change issues have been linked with other club-good agreements that limit the gains of cooperation only to members of the agreement, for example, on energy, sustainable development, R&D, international trade, etc. (Stavins et al., 2014).

Given the interactions between trade and climate policy and the impact of international trade on global GHG emissions, there has been significant research on how international trade policy can be used complementary to a climate policy to help address the problem of free-riding in IEAs. Game theoretic literature on coalition formation shows that trade restrictions, in general, can increase participation in international climate agreements by acting as a deterrent to free-riding incentives when applied to outsiders of a coalition (Barrett, 1997; Barrett and Stavins, 2003; Kempfert, 2004 cited in Lessmann et al., 2009). An example is the Montreal Protocol that provides for a ban on trade in controlled goods. Since a ban on embedded-carbon products is impossible, trade-restricting tariffs and trade sanctions like border carbon adjustments have subsequently been proposed as a supplement to unilateral climate policies to affect participation and as well as ease competitiveness loss in abating sectors.

Border carbon adjustments feature prominently in recent literature as an option for reducing leakage and protecting exposed sectors from the competitive disadvantage borne out of unilateral climate policies. Most economic modelling literature focuses on their effectiveness at reducing leakage and ensuring fairer competition at sectoral and aggregate levels. There has, however, been no unequivocal consensus over the effectiveness of border measures. On one hand, some argue that border carbon adjustments have a positive impact on reducing leakage (Branger and Quirion, 2014; Carbon Trust, 2010; Monjon and Quirion, 2011; see also Zhang, 2012, pp. 257); leakage tends to decline by 2-12% following their introduction (Boehringer et al., 2012). On the other hand, some studies are skeptical about the ability of border measures to reduce leakage significantly (Fischer and Fox, 2012; McKibbin and Wilcoxen, 2008). According to them, the overall benefits from employing border carbon adjustments may be too small to justify the administrative hurdles and the contractionary effect on international trade. Further, all these studies agree that any reduction in leakage comes at the behest of contracted production in EITE industries in the abating. In other words, the effectiveness of border adjustments in preventing competitiveness loss is found to be small with the exception of Dissou and Eyland (2011) who find that an import adjustment can significantly reduce the competitive disadvantage of domestic EITE industries. These studies highlight the fact that border carbon adjustments cannot always reduce leakage as well as loss of competitiveness; there is usually as trade-off between the two depending on the specific design of the adjustment. The effectiveness of a border measure hinges on its scope and coverage, whether it includes export adjustments, as well as on the benchmark used for calculating embedded carbon content (Zhang, 2012). This is confirmed in studies that compare several configurations of border carbon adjustments including import tariffs, export rebates, a full border adjustment, output-based rebating, etc. (Fischer and Fox, 2012; Monjon and Quirion, 2011).

Other studies look at the strategic effects of border measures on an international level. A political game theory model of border carbon adjustments developed by Helm et al. (2012) shows that a move by a region with near-unilateral carbon pricing to impose such adjustments on imports can trigger a strategic response from non-abating regions to impose export adjustments or a matching carbon price of their own. Border measures may thus accelerate the global dissemination of near-equal carbon prices.

Furthermore, departing from general equilibrium models like Dissou and Eyland (2011), Fischer and Fox (2012) which do not allow for any climate policy reactions of the countries facing a border adjustment, Eyland and Zaccour (2012, 2014) develop a model à la Brander and Spencer's (1985)[2] that allows for strategic interactions between countries' tariffs after an import adjustment is implemented. Using a simplified two-country model, the authors show that border tariffs may be a credible threat to induce countries with smaller/non-existent mitigation commitments to change their climate policy.

There has, however, been little research on the impact of border carbon adjustments, a type of trade sanction, on the various aspects of coalition formation in IEAs. Eichner and Pethig (2013b) examine the impact of trade tariffs on coalition formation. This is, however, a study of IEA stability under the type of trade policy that derives from the model's assumptions; a border carbon adjustment (on imports or otherwise) is not explicitly modeled. Further, direct evidence is insufficient to reach a definite conclusion of whether border measures enhance participation. Therefore, to contribute to the discussion of how border measures can affect climate policy, with respect to curbing free-riding incentives, I construct a model that analyzes the impact of an import adjustment on non-signatories on participation and stability in an IEA. The model developed in this paper serves as an extension to Eyland and Zaccour's (2012) two-country setup. As opposed to the authors' model, my model operates within a generalized n-country setting where each country's welfare function comprises of consumptive utility, firm profits, tariff revenue and the environmental damage function. Lessman et al. (2009) have also investigated the impact of an import adjustment on cooperation in an IEA. However, unlike my model, theirs neither accounts for the climate policy of non-signatories nor allows for the strategic optimization of carbon tariffs of signatories and non-signatories in the presence of the border adjustment.

[2] Eyland and Zaccour (2012) base their model on Brander and Spencer's (1985) analysis of strategic trade policy in the presence of trade tariffs and extend it by introducing environmental concerns.

5. The Model

To assess the impact of a border carbon adjustment on participation and stability in IEAs, I extend the duopoly trade model of Eyland and Zaccour (2012) to an n-country model. The paper will examine the equilibrium size and stability of IEAs as well as global welfare and emissions in the presence of border adjustments compared to the scenario where such adjustments are absent. The border adjustment is levied by signatories to an IEA on the imports from non-signatories.

I assume that there are n ex-ante symmetric countries in the world economy i.e. N = (1, 2, …, n). Each country consists of one firm that produces a homogeneous good and has the option of levying a domestic carbon tariff (tax or subsidy) on the production of that good. This tariff corresponds to an emission-based tariff since it is aimed at pricing carbon emissions generated from the production of that good. Each country chooses its domestic carbon tariff such that its domestic welfare is maximized. Further, each country has the additional policy option of levying a border tariff adjustment (BTA) on imports. The import tariff serves as a carbon-pricing mechanism to correct for the different carbon prices in other countries. The BTA is assumed to always be non-negative.[3]

The welfare of any country j consists of the consumer utility u_j, the producer surplus i.e. the firm profits denoted by π_j, the domestic carbon tariff revenue TR, the border tariff revenue BTR and the environmental damages D as follows,

$$W_j = u_j + \pi_j + TR_j + BTR_j - D \qquad j = (1, 2, \dots, n) \qquad (1)$$

The quantity of output of the good (supply) and quantity consumed (demand) by any country j is denoted by q_j^s and q_j^d respectively. The total quantity Q of the good in the world economy can be expressed as the total supply or the total demand of the good, given as below,

$$Q = \sum_{j=1}^{n} q_j^{\,d} = \sum_{j=1}^{n} q_j^{\,s} \qquad (2)$$

I adopt the following inverse demand function,

$$P_j(q_j) = \alpha - \beta q_j^{\,d}$$

where P, price of the good, depends on the quantity of good consumed i.e. demanded by any country. α and β are strictly positive parameters.

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[3] **When carbon tariffs of the countries involved are equal, the BTA will be zero.**

Given the inverse demand, the consumer preferences of the representative consumer in any country, are given by the following utility function,

$$u_j(q_j) = \frac{\beta}{2}(q_j^{\,d})^2 \tag{3}$$

t_j denotes the per-unit domestic carbon tariff levied on the firm in any country j. The imports from a country are also subject to a per-unit import tariff given by,

$$BTA = \delta(t_j - t_i) \tag{4}$$

where δ determines the percentage of the difference between the domestic tariffs of the importing and exporting country that may be imposed as a border tariff. Since the BTA is assumed to be non-negative, the domestic carbon tariff in the importing country must be greater than (or equal to) that in the exporting country.

δ can either be exogenously determined by an international body, say, WTO or be decided endogenously as part of an environmental agreement. A BTA that is acceptable under international trade laws requires that a border tariff on imports necessarily be less than or equal to the domestic carbon tariff faced by the producers of the importing country. In this paper, I consider the case of δ = 1 which corresponds to full adjustment of the domestic carbon price difference between two countries.

Let c denote the constant per-unit marginal cost of producing the good. The profit function of any firm j is then given by,

$$\pi_j(q_j, t_j) = (P_j - c - t_j)\sum_{j=1}^{n} q_{ij} - \delta(t_j - t_i)\sum_{j\neq i}^{n} q_{ij} \tag{5}$$

where q_{ij} is the quantity supplied from country i to j for all i, j ∈ N. When j ≠ i, the imports from i to j are taxed at the border if country i is a non-signatory and country j is a signatory.

Note that, $q_j^{\,d} = q_{1j} + q_{2j} ... + q_{nj}$, and $q_j^{\,s} = q_{j1} + q_{j2} ... + q_{jn}$

Any country j has two sources of tariff revenue i.e. domestic carbon tariff revenue and the revenue generated by the BTA on imports given respectively by,

$$TR_j = t_j \sum_{j=1}^{n} q_{ij} \quad \text{and} \quad BTR_j = \delta(t_j - t_i)\sum_{j\neq i}^{n} q_{ij} \tag{6}$$

Since countries are symmetric, they face the same amount of environmental damage from trans-boundary pollution caused by emissions during production.

For simplification, I adopt the following linear specification such that the damage cost is increasing in total production,

$$D(\mathrm{Q}) = \gamma Q \tag{7}$$

where γ is the damage parameter and is strictly positive.

The welfare, therefore, of any country j is given by,

$$W_j(q_j, t_j) = u_j(q_j) + \pi_j(q_j, t_j) + t_j \sum_{j=1}^{n} q_{ij} + \delta(t_j - t_i) \sum_{j \neq i}^{n} q_{ij} - D(Q) \tag{8}$$

5.1 Environmental Agreement Model Setup

Coalition formation occurs in a two-stage game where in the first stage some players choose to participate in the IEA and the rest remain non-signatories. The second stage involves decisions about abatement and choice of distribution of gains from cooperation.

For this paper, I use the coalition formation rules of the Open Membership Single Coalition Game (OMSCG) to describe the process of coalition formation in an IEA. The assumptions of OMSCG require that in the first stage, countries choose membership simultaneously and all non-signatories play as singletons. Countries can only form one coalition and membership is open to all players. In the second stage, once a coalition has formed all players choose their abatement strategies simultaneously. Coalition members, acting as one player, jointly set abatement targets and maximize aggregate welfare. All non-signatories maximize individual welfare. To calculate equilibrium under partial cooperation, the game is solved for a Partial Agreement Nash Equilibrium (PANE) which corresponds to signatories cooperating within the coalition but playing Nash against non-signatories.

Out of n countries let there be m countries that are members of a climate coalition; all other countries act in a non-cooperative fashion. For simplifying the analysis, I lump signatories as being first m countries making up the climate coalition group denoted by L = (1, 2, …, m). The non-signatories are lumped together into a group denoted by NL = (m+1, …, n).

Proceeding with the setting that all countries within one group are treated equally, it is convenient to assume that the coalition jointly sets the domestic carbon tariff for all members as $t_j = t_L$ for all j ∈ L and that the domestic carbon tariff of all non-signatories is $t_j = t_{NL}$ for all j ∈ NL.

As mentioned before, the difference in domestic carbon tariffs of signatories and non-signatories is levied as a BTA. Further, for the purposes of this research, it is assumed that the use of the border tariff adjustment is only available to the signatories to the IEA and is levied only on the non-signatories.

5.1.1 Coalition Formation without Border Tariff Adjustments

As given by (1) the welfare of any country consists of its consumer surplus, firm profits, revenue from domestic carbon tariff, revenue from BTA tariff and the damages caused by emissions from total production.

I first look at the case without BTAs. The representative consumer surplus and environmental damage function is equal for all countries as given by (3) and (7) respectively. However, the firm profits and total tariff revenue now depend on whether its country is signatory or a non-signatory. The notation L and NL are used to signify the coalition and the non-coalition groups respectively.

Profits for its firm and domestic tariff revenue if country j is a signatory to the IEA are respectively given by,

$$\pi_j^{\ L} = (P_j - c - t_L)\sum_{j=1}^{n} q_{ij} \tag{9}$$

$$TR_j^{\ L} = t_L \sum_{j=1}^{n} q_{ij} \tag{10}$$

Similarly, profits for its firm and domestic tariff revenue if country j is a non-signatory are respectively given by,

$$\pi_j^{\ NL} = (P_j - c - t_{NL})\sum_{j=1}^{n} q_{ij} \tag{11}$$

$$TR_j^{\ NL} = t_{NL} \sum_{j=1}^{n} q_{ij} \tag{12}$$

The welfare of a country j if it is a signatory (∈ L) or a non-signatory (∈ NL) respectively is given by,

$$W_j^{\ L} = u_j(q_j) + (P_j - c - t_L)\sum_{j=1}^{n} q_{ij} + t_L \sum_{j=1}^{n} q_{ij} - D(\mathrm{Q}) \tag{13}$$

$$W_j^{\ NL} = u_j(q_j) + (P_j - c - t_{NL})\sum_{j=1}^{n} q_{ij} + t_{NL} \sum_{j=1}^{n} q_{ij} - D(\mathrm{Q}) \tag{14}$$

The game is solved in the reverse order to determine the equilibrium welfare of all countries. In the second stage of the game, taking as given the tariff rates of coalition and non-coalition counties, each firm chooses output so as to maximize its profit. Once equilibrium outputs are determined, in the first stage, the coalition countries choose the carbon tariff such aggregate welfare of the coalition is maximized taking as given the tariff rates of the non-signatories

The coalition's maximizes its objective function which is the aggregate, **$W^L = m\ W_j^L$** i.e. $\underset{t_L}{Max}\, mW_j^{L}$. The non-signatories maximize individual welfare i.e. $\underset{t_{NL}}{Max}\, W_j^{NL}$.

5.1.2 Coalition Formation with Border Tariff Adjustments

Now I look at the case where the environmental agreement includes a BTA on imports. In this scenario, all imports from the non-signatories are subject to a per-unit border tariff levied by the signatories of the coalition. The BTA is fully adjusted for the difference between the domestic carbon tariffs of the signatories and non-signatories, given by,

$$BTA = (t_L - t_{NL}) \tag{15}$$

The firm profits and total tariff revenue of signatories as well as non-signatories must now also account for the BTA. The superscript B is added to distinguish this case from the case without BTAs.

Profits for its firm if country j is a signatory to the IEA is given by,

$$\pi_j^{LB} = (P_j - c - t_L)\sum_{j=1}^{n} q_{ij} \tag{16}$$

Total tariff revenue for the signatory country is the sum of domestic carbon tariff revenue TR_j^{LB} and border tariff revenue BTR_j^{LB} as given below,

$$TR_j^{LB} = t_L \sum_{j=1}^{n} q_{ij} \quad \text{and} \quad BTR_j^{LB} = (t_L - t_{NL})\sum_{j\neq i}^{n} q_{ij} \tag{17}$$

Similarly, profits for its firm and tariff revenue if the country j is a non-signatory are as follows,

$$\pi_j^{NLB} = (P_j - c - t_{NL})\sum_{j=1}^{n} q_{ij} - (t_L - t_{NL})\sum_{j\neq i}^{n} q_{ij} \tag{18}$$

$$TR_j^{NLB} = t_{NL}\sum_{j=1}^{n} q_{ij} \tag{19}$$

The welfare of a country j that is a signatory in the presence of BTAs is therefore,

$$W_j^{LB} = u_j(q_j) + (P_j - c - t_L)\sum_{j=1}^{n} q_{ij} + t_L\sum_{j=1}^{n} q_{ij} + (t_L - t_{NL})\sum_{j\neq i}^{n} q_{ij} - D(\mathrm{Q}) \tag{20}$$

The welfare of a country j that is a non-signatory in the presence of BTAs is therefore,

$$W_j^{NLB} = u_j(q_j) + (P_j - c - t_{NL})\sum_{j=1}^{n} q_{ij} - (t_L - t_{NL})\sum_{j\neq i}^{n} q_{ij} + t_{NL}\sum_{j=1}^{n} q_{ij} - D(\mathrm{Q}) \qquad (21)$$

To determine the equilibrium, the game is solved in reverse order. In the second stage, firms choose output such that its profits are maximized taking as given the tariff rates of coalition and non-coalition countries, and the BTA.

Once equilibrium output is determined, in the first stage, the coalition chooses the carbon tariff such that its aggregate output is maximized taking as given the tariffs of the non-signatories. The coalition's maximizes its objective function which is the aggregate, $\mathbf{W^{LB} = m\ W_j^{LB}}$ i.e. $\underset{t_L}{Max}\, m W_j^{LB}$. The non-signatories maximize individual welfare i.e. $\underset{t_{NL}}{Max}\, W_j^{NLB}$.

For given parameters α, β, δ, γ and n, the equilibrium is uniquely determined by the coalition size m. The determination and analyses of all equilibrium quantities henceforth are done using the computer algebra software Maple.

6. The n- Country Game

With n countries in the world, there can be three coalition structures. The first structure corresponds to a coalition of all singletons i.e. C_1: ({1}, {2}… {n}). The second coalition structure corresponds to the social optimum i.e. the grand coalition C_2: ({1, 2… n}). The third coalition structure is the one with partial cooperation in an environmental agreement. As mentioned before, I assume that the first m countries are signatories to the coalition and the rest i.e. n – m countries are non-signatories. Therefore, the coalition structure can be denoted by, C_3: ({1, 2, 3,…, m}, {m+1, m+2,…, n}).

The use of a BTA is relevant only for the coalition structure with partial cooperation. This is because BTAs cannot be applied to a coalition structure where all countries play as singletons i.e. when there is no IEA or to a grand coalition structure where all countries in the world economy are signatories to an IEA.

First, I derive the equilibrium carbon tariff rates, equilibrium outputs and hence equilibrium welfare for all three coalition structures. C_3 will have different equilibrium results depending on the absence or presence of BTAs.

6.1 Coalition Structure C_1

In the coalition structure comprised of all singletons, i.e. when no IEA is formed, the use of BTAs is irrelevant. Equilibrium is characterized by the non-cooperative Nash equilibrium; each government sets its domestic carbon tariff taking as given the domestic carbon tariffs of other countries.

In the first stage of the game, taking as given the output of all firms in the world economy, each country chooses domestic carbon tariff such that its individual welfare is maximized i.e. $\underset{t_j}{Max} W_j$. Since countries are ex-ante symmetric, the welfare of any one country can represent that of all other individual countries in the model.

The welfare of any country j, say j = 1, is given by,

$$W_1 = u_1(q_1{}^d) + \pi_1 + t_1 \sum_{j=1}^{n} q_{1j} - D(\text{Q})$$

$$.... = u_1(q_1{}^d) + \sum_{j=1}^{n} P_j q_{1j} - c\sum_{j=1}^{n} q_{1j} - t_1 \sum_{j=1}^{n} q_{1j} + t_1 \sum_{j=1}^{n} q_{1j} - D(\text{Q}) \tag{22}$$

In the second stage of the equilibrium game, country 1's firm chooses its output such that its profits are maximized taking as given the carbon tariffs of all countries. The game is solved in the reverse order.

This firm's profit π_1, is given by,

$$\pi_1 = \sum_{j=1}^{n} \mathrm{P}_j\, q_{1j} - (c+t_1)\sum_{j=1}^{n} q_{1j} = (P_1 q_{11} + P_2 q_{12} ... + P_n q_{1n}) - (c+t_1)\sum_{j=1}^{n} q_{1j} \qquad (23)$$

The profits of firms of all other countries can be represented similarly as above. For example the profit of the firm in country n is given by,

$$\pi_n = \sum_{j=1}^{n} \mathrm{P}_j\, q_{nj} - (c+t_n)\sum_{j=1}^{n} q_{nj} = (P_1 q_{n1} + P_2 q_{n2} ... + P_n q_{nn}) - (c+t_n)\sum_{j=1}^{n} q_{nj} \qquad (24)$$

To maximize the profit in (23), the first order conditions for the market in country 1 are obtained by differentiating π_1 by q_{11}, π_2 by q_{21} and so on up to π_n by q_{n1}. They are as follows,

$$\begin{aligned}
&\alpha - 2\beta q_{11} - \beta q_{21} - ... - \beta q_{n1} - c - t_1 = 0\\
&\alpha - 2\beta q_{21} - \beta q_{11} - ... - \beta q_{n1} - c - t_2 = 0\\
&.\\
&.\\
&\alpha - 2\beta q_{n1} - \beta q_{11} - ... - \beta q_{n-1,1} - c - t_n = 0
\end{aligned} \qquad (25)$$

Since the good is homogenous, the consumers of country 1 do not care about the origin of the good. Therefore, the supply of the good from countries except 1 can be denoted by $q_{i-1,\,1}$. The first order conditions then, can be re-written as,

$$\begin{aligned}
&\alpha - 2\beta q_{11} - (n-1)\beta q_{i-1,1} - c - t_1 = 0\\
&\alpha - \beta q_{11} - n\beta q_{i-1,1} - c - t_2 = 0\\
&.\\
&.\\
&\alpha - \beta q_{11} - n\beta q_{i-1,1} - c - t_n = 0
\end{aligned} \qquad (26)$$

Similarly, the supply of good to country 1 from all countries except 2 can be denoted by $q_{i-2,\,1}$ and so on for all n giving n system of equations as above. The n systems of equations are used to solve for quantities supplied to 1 from all n countries.

Solving the above system of equations for all quantities supplied to country 1 as a function of tariff rates gives the following,

$$q_{11} = \frac{\alpha - c - nt_1 + \sum_{j\neq 1}^{n} t_j}{(n+1)\beta},\quad q_{21} = \frac{\alpha - c - nt_2 + \sum_{j\neq 2}^{n} t_j}{(n+1)\beta}, ...\ q_{n1} = \frac{\alpha - c - nt_n + \sum_{j\neq n}^{n} t_j}{(n+1)\beta} \qquad (27)$$

The same process of using first order conditions as done above can be repeated for markets in all n countries. The quantities so obtained can be generalized in the following expression.

For any country i ϵ N,

$$q_{ij} = \frac{\alpha - c - nt_i + \sum_{j \neq i}^{n} t_j}{(n+1)\beta} \tag{28}$$

The above expression is used to derive the total quantity of output (supply) and total quantity consumed (demand) by each country. For any country i ϵ N[4],

$$q_i^s = \frac{\mathrm{n}(\alpha - c - nt_i + \sum_{j \neq i}^{n} t_j)}{(n+1)\beta} \quad \text{and} \quad q_i^d = \frac{\mathrm{n}\,\alpha - nc - \sum_{j=1}^{n} t_j}{(n+1)\beta} \tag{29}$$

Note that output in any country is decreasing in domestic tariff and increasing in foreign carbon tariff. Further, the negative effect of domestic tariff on output is n times greater than the positive effect of foreign tariff.

The total quantity of the good, Q, available in the world economy is the sum of all consumption (or output) of the good given by,

$$Q = \frac{\mathrm{n}(\mathrm{n}\,\alpha - nc - \sum_{j=1}^{n} t_j)}{(n+1)\beta} \tag{30}$$

Next, I insert the quantities obtained above into the welfare function in (22) and maximize the resultant expression with respect to country 1's domestic carbon tariff t_1. The first order condition so obtained is a reaction function highlighting the strategic interaction between the tariffs of each country.

It is given by the following expression,

$$(2n^2 - 1)t_1 + (n^2 - n - 1)\sum_{j \neq 1}^{n} t_j = -n^2\alpha + n^2 c + n^2(n+1)\gamma \tag{32}$$

Note that the domestic carbon tariff in country 1 has a negative correlation with the tariffs in all other countries. This implies that when foreign tariff increases, domestic tariff decreases proportionally.

[4] Note that even though the subscript j has been used to denote countries in the quantities of output and consumption up to this point, the terms q_j and q_i denote the same thing. The subscript has been changed to i for convenience and to avoid confusion while reading expressions containing the term t_j.

Repeating the same welfare maximization procedure as above for all n countries gives the following system of reaction functions,

$$
\begin{aligned}
&(2n^2-1)t_2+(n^2-n-1)\sum_{j\neq 2}^{n} t_j = -n^2\alpha + n^2 c + n^2(n+1)\gamma \\
&. \\
&. \\
&(2n^2-1)t_n+(n^2-n-1)\sum_{j\neq n}^{n} t_j = -n^2\alpha + n^2 c + n^2(n+1)\gamma
\end{aligned}
\tag{33}
$$

Solving these reaction functions highlights the fact that in the trivial coalition structure with each country playing Nash against all other players, the equilibrium is $t_1^* = t_2^* = \ldots = t_n^*$. That is, all countries choose the same domestic tariff rate in equilibrium for all j ϵ N is given by,

$$
t_j^{\,*} = \frac{-n\alpha + nc + (n+1)\gamma}{n^2} \tag{34}
$$

The sign of the above expression depends on specific values of α, c and γ. For the case where γ is 0 i.e. in the absence of environmental concerns, for t_j to be positive i.e. a tariff, the value of c must be greater than that of α, and vice versa for it to be a subsidy.

Equilibrium output of each country is obtained by inserting the value of the tariff in the expressions for output and consumption. The expressions so obtained are,

$$
q_j^{\,s*} = \frac{n\alpha - nc - \gamma}{n\beta} \quad \text{and} \quad q_j^{\,d*} = \frac{n\alpha - nc - \gamma}{n\beta} \tag{35}
$$

where q_j^{s*} and q_j^{d*} represent the quantity of good produced and quantity of good consumed in each country in equilibrium. The value of these equilibrium quantities depends on α, β, c and γ.

Since countries levy equal domestic carbon tariff and produce equal quantity of the good in equilibrium, equilibrium welfare of all countries is also equal. It is obtained by inserting the expressions for equilibrium quantities in (35) into the expression for welfare of country 1 in (22).

The welfare so obtained can be generalized, such that for any country j ∈ N,

$$
W_j^{\,*} = \frac{[(\alpha-c)^2 - 2n\gamma(\alpha-c) + \dfrac{(2n^2-1)}{n^2}\gamma^2]}{2\beta} \tag{36}
$$

6.2 Coalition Structure C_2

Next, I repeat the game as played above for the coalition structure C_2 i.e. the grand coalition where all three countries are signatories to an IEA; there are no BTAs in this scenario. However, now in the first stage of the game, the signatories choose carbon tariffs such the aggregate welfare of the coalition L is maximized. That is,

$$\underset{t_j}{Max} W^L = \underset{t_j}{Max}(\sum_{j=1}^{n} W_j^{\,L})$$

The first order conditions of profit maximization for each market in the singletons coalition structure in equation (25) are the same for the grand coalition structure. Therefore, I use the expressions for output derived previously in (28), (29) and (30) in this scenario as well.

The aggregate welfare of the coalition is the sum of individual welfares of its member countries and is given by,

$$W^L = \sum_{j=1}^{m} u_j(q_j^{\,d}) + (\sum_{j=1}^{n} P_j q_{1j} + \sum_{j=1}^{n} P_j q_{2j} + \ldots + \sum_{j=1}^{n} P_j q_{mj}) - c\sum_{j=1}^{n} q_j^{\,s} - \sum_{j=1}^{n} t_j q_j^{\,s} + \sum_{j=1}^{n} t_j q_j^{\,s} - nD(Q) \tag{37}$$

The aggregate welfare above is maximized with respect to all tariff rates i.e. t_j for all j ϵ N. The n first order conditions, so obtained are given by,

$$\begin{aligned}
\frac{\partial W^L}{\partial t_1} &= -n\alpha + nc - nt_1 - n\sum_{j\neq 1}^{n} t_j + n^2(n+1)\gamma = 0 \\
\frac{\partial W^L}{\partial t_2} &= -n\alpha + nc - nt_2 - n\sum_{j\neq 2}^{n} t_j + n^2(n+1)\gamma = 0 \\
&. \\
&. \\
\frac{\partial W^L}{\partial t_n} &= -n\alpha + nc - nt_n - n\sum_{j\neq n}^{n} t_j + n^2(n+1)\gamma = 0
\end{aligned} \tag{38}$$

Since, I have assumed that all signatories to the coalition levy the same domestic carbon tariff t_L on its firms i.e. $t_j = t_L$, I impose this symmetry condition in the system of reaction functions above in (38). The solution gives the equilibrium carbon tariff rate levied by all signatories as the following,

$$t_j^{\,*} = t_L^{\,*} = \frac{-\alpha + c + n(n+1)\gamma}{n} \tag{39}$$

This equilibrium tariff rate of the grand coalition is used to obtain the equilibrium output and consumption quantities of each country which are,

$$q_j^{s*} = \frac{\alpha - c - n\gamma}{\beta} \quad \text{and} \quad q_j^{d*} = \frac{\alpha - c - n\gamma}{\beta} \tag{40}$$

Since the grand coalition is the socially optimum scenario, we can intuit that the equilibrium quantity of good produced by the grand coalition would be the lowest among all other scenarios of partial cooperation. This quantity obtained in (40) therefore, serves as the non-negativity constraint that the parameters α, β, γ and n must adhere to. That is,

$$q_j^{s*} = q_j^{d*} = \frac{\alpha - c - n\gamma}{\beta} > 0$$

In other words, $\frac{\gamma}{(\alpha - c)} < \frac{1}{n}$. I now define a new parameter z equal to the right-hand side of this inequality. The parameter ratio z is therefore defined over the interval [0, 1/n) and denotes all possible combinations of these three parameters.

Since the equilibrium carbon tariff rate and output of all signatories are equal, the welfare of any one country can represent that of each of the other countries. The quantities obtained in (40) are inserted into (22) to get the equilibrium welfare of a signatory. For any j ϵ N,

$$W_j^{L*} = \frac{[(\alpha - c)^2 - 2n\gamma(\alpha - c) + n^2\gamma^2]}{2\beta} \tag{41}$$

Note that moving from the singletons coalition structure to the grand coalition, the equilibrium carbon tariff rate has increased however the individual welfare of each country has also increased considerably.

6.3 Coalition Structure C_3

6.3.1 Without Border Tariff Adjustments

I now solve the game for the coalition structure C_3, i.e. the scenario of partial cooperation where only some countries are signatories to the IEA denoted by L = (1, 2, …, m) and the non-signatories denoted by the group NL = (m+1, m+2, …, n).

I use the generalized quantity obtained for the singletons coalition structure in equation (28). Therefore, the quantity of output q_j^s, quantity consumed q_j^d by each country and the total quantity of the good in the world market Q used in this scenario are the same as derived for the singletons coalition in equations (29) and (30).

In this coalition structure, the signatory countries cooperate within the coalition but act non-cooperatively with the non-signatory countries. Further, all non-signatories also play Nash against each other.

As mentioned before, the signatory countries choose their strategies in order to maximize aggregate welfare of the coalition whereas the non-signatories maximize individual welfare. That is,

$$\underset{t_j}{Max} W^L = \underset{t_j}{Max}(\sum_{j=1}^{m} W_j^{\ L}) \text{ for } j \in L \text{ and } \underset{t_j}{Max} W^{NL} = \underset{t_j}{Max}(\sum_{j=m+1}^{n} W_j^{\ NL}) \text{ for } j \in NL$$

Now, the aggregate welfare for the coalition is given by the expression in (42) below,

$$W^L = \sum_{j=1}^{m} u_j(q_j^{\ d}) + (\sum_{j=1}^{n} P_j q_{1j} + \sum_{j=1}^{n} P_j q_{2j} + ... + \sum_{j=1}^{n} P_j q_{mj}) - c\sum_{j=1}^{m} q_j^{\ s} - \sum_{j=1}^{m} t_j q_j^{\ s} + \sum_{j=1}^{m} t_j q_j^{\ s} - m\mathrm{D(Q)}$$

The values of quantities from equations (28), (29) and (30) are inserted into (42) and the resultant expression is maximized with respect to all signatory tariff rates i.e. t_j for all j ϵ L. The reaction function so obtained is given by,

$$\begin{aligned} &-n(n-m+1)\alpha + n(n-m+1)c + m\sum_{j=1}^{m} t_j - 2n(n-m+1)\sum_{j=1}^{m} t_j - n(2m-n-1)\sum_{j=m+1}^{n} t_j \\ &+ nm(n+1)\gamma = 0 \end{aligned} \quad (43)$$

Further, the individual welfare of any one non-signatory, say n, can represent that of all other non-signatories since countries are ex-ante symmetric. The welfare of n is given by,

$$W_n = u_n(q_n^{\ d}) + \sum_{j=1}^{n} P_j q_{nj} - (c + t_n)\sum_{j=1}^{n} q_{nj} + t_n \sum_{j=1}^{n} q_{nj} - D(\mathrm{Q}) \quad (45)$$

Inserting the quantities of output and consumption from equations (28), (29) and (30) into the welfare function in (45) and maximizing the resultant expression with respect to t_n gives the following reaction function,

$$-n^2\alpha + n^2 c - n(n+1)t_n - (n^2 - n - 1)\sum_{j=1}^{n} t_j + n(n+1)\gamma = 0 \quad (46)$$

Now, since I have assumed that all signatories and non-signatory countries levy the same carbon tariff within each group i.e. $t_j = t_L$ for j ϵ L and $t_j = t_{NL}$ for j ϵ NL, the reaction functions in (43) and (46) can be rewritten as the following expressions.

For signatories and non-signatories respectively,

$$-n(n-m+1)\alpha + n(n-m+1)c - m(2n^2 - 2nm + 2n - m)t_L + (n-m)(n^2 - 2nm + n + m)t_{NL}$$
$$+nm(n+1)\gamma = 0$$

and (47)

$$-n^2\alpha + n^2 c - m(n^2 - n - 1)t_L - (n^3 - n^2 m + nm + m)t_{NL} + n(n+1)\gamma = 0$$

Solving the two welfare maximization conditions obtained for the coalition and the non-signatory in (47) above gives the equilibrium tariff rates[5] and equilibrium quantities of output and consumption.

The equilibrium tariff for the signatories is,

$$t_L^{\,*} = \frac{\begin{array}{c}-(\alpha-c)(3n^2m^2 - 5n^3n + 2n^4 - 2nm^2 + 2n^3 - m^2 + 2nm + m) \\ +\gamma n(n+1)(\mathrm{n}\, m^2 - n^2 m - 3m^2 + 3nm - n^2 - n))\end{array}}{m(4n^2m^2 - 7n^3m + 3n^4 - 4nm^2 + 2n^2m + 2n^3 - 4m^2 + 7nm - 2n^2 + 2m - n)} \tag{48}$$

The equilibrium tariff for non-signatories is,

$$t_{NL}^{\,*} = \frac{\begin{array}{c}(\alpha-c)(n^2m - n^3 + 2nm - 2n^2 - 2n + m - 1) \\ -\gamma n(n^2m + 2nm - 2n^2 - 4n + m - 2)\end{array}}{(4n^2m^2 - 7n^3m + 3n^4 - 4nm^2 + 2n^2m + 2n^3 - 4m^2 + 7nm - 2n^2 + 2m - n)} \tag{49}$$

Equilibrium output and consumption of signatories and non-signatories is obtained by inserting the tariffs in equation (48) and (49) into the expression of output and consumption in (29).

---

[5] **The uniqueness of the equilibrium can be verified by,**

$$\frac{\partial^2 W_j^{\,L}}{\partial (t_L)^2} = \frac{4nm^2 - 4n^2m + 2m^2 - 4nm}{2(n+1)^2\beta} < 0 \quad \text{and} \quad \frac{\partial^2 W_j^{\,NL}}{\partial (t_{NL})^2} = \frac{4nm^2 - 4n^2m + 2m^2 - 2n^2}{2(n+1)^2\beta} < 0$$

$$\frac{\partial^2 W_j^{\,L}}{\partial t_L \partial t_{NL}} = \frac{-4nm^2 + 6n^2m - 2n^3 - 2m^2 + 4nm - 2n^2}{2(n+1)^2\beta} \;,\; \frac{\partial^2 W_j^{\,NL}}{\partial t_{NL} \partial t_L} = \frac{-4nm^2 + 2n^2m - 2m^2}{2(n+1)^2\beta}$$

The determinant of the Hessian is equal to

$$\triangle^L = \frac{-n^2(n-m)^2}{\beta^2(n+1)^2} < 0 \;,\; \triangle^{NL} = \frac{-n^2m^2}{\beta^2(n+1)^2} < 0$$

Equilibrium output for a signatory i.e. for all $j \in L$,

$$q_j^{s*} = \frac{\begin{array}{c} -(\alpha - c)(-3n^2m^2 + 5n^3m - 2n^4 + 4m^3 - 4nm^2 + 2n^2m - 2n^3 - m^2 - m)\,\mathrm{n} \\ +\gamma n^2(n^2m^2 - n^3m + 4m^3 - 8nm^2 + 5n^2m - n^3 - 5m^2 + 6nm - 2n^2 - n) \end{array}}{\beta m(4n^2m^2 - 7n^3n + 3n^4 - 4nm^2 + 2n^2m + 2n^3 - 4m^2 + 7nm - 2n^2 + 2m - n)} \quad (50)$$

Equilibrium output for a non-signatory i.e. for all $j \in NL$,

$$q_j^{s*} = \frac{\begin{array}{c} -(\alpha - c)(n^2m - n^3 + 4m^2 - 4nm - m - 1)\,\mathrm{n} \\ +\gamma n^2(n^2m + 4m^2 - 4nm + n^2 - n - m - 2) \end{array}}{\beta(4n^2m^2 - 7n^3m + 3n^4 - 4nm^2 + 2n^2m + 2n^3 - 4m^2 + 7nm - 2n^2 - n + 2m)} \quad (51)$$

Equilibrium consumption of each country is the same, irrespective of it being a signatory or non-signatory and is given by,

$$q_j^{\mathrm{d}*} = \frac{\begin{array}{c} (\alpha - c)(4nm^2 - 7n^2m + 3n^3 - 4m^2 + 2nm + 2n^2 + m + 1)\,\mathrm{n} \\ -\gamma n(4m^2 - 6nm + 3n^2 - 2m + 3n) \end{array}}{\beta(4n^2m^2 - 7n^3m + 3n^4 - 4nm^2 + 2n^2m + 2n^3 - 4m^2 + 7nm - 2n^2 + 2m - n)} \quad (52)$$

The equilibrium quantities of output and consumption obtained above are inserted into the expression for welfare expressions in (22) and (45) to derive the equilibrium welfare of a signatory $\mathbf{W_j^{L*}}$ and a non-signatory $\mathbf{W_j^{NL*}}$ respectively for the non-BTA scenario.[6]

The welfare of a signatory is strictly concave in t_L and strictly convex in t_{NL} (see Footnote 4) i.e. it is negatively affected by an increase its own tariff and positively affected by non-signatory tariff. Further, the negative impact of t_L on signatory welfare is greater than the positive impact of non-signatory tariff. The same analysis holds for non-signatory welfare as well.

6.3.2 With Border Tariff Adjustments

To highlight the effect of a BTA on coalition formation, the game in the previous section is now extended by adding the BTA revenue that is received by a coalition country of the group L = (1, 2, …, m) from goods imported from a non-signatory of the group NL = (m+1, m+2, …, n).

[6] The equilibrium welfares expressions are very long. I refrain from printing; they are available on request.

Since countries are ex-ante symmetric, the welfare of any one signatory, say 1, can represent that of all other signatories. The welfare country 1 with BTAs, is given by,

$$W_1^L = u_1(q_1{}^d) + \sum_{j=1}^{n} P_j q_{1j} - (c+t_1)\sum_{j=1}^{n} q_{1j} + t_1 \sum_{j=1}^{n} q_{1j} + \sum_{i=m+1}^{n} (t_1 - t_i) q_{i1} - D(\mathrm{Q}) \quad (53)$$

Similarly the welfare of any one non-signatory with BTAs, say n, is given by,

$$W_n = u_n(q_n{}^d) + \sum_{j=1}^{n} P_j q_{nj} - (c+t_n)\sum_{j=1}^{n} q_{nj} + t_n \sum_{j=1}^{n} q_{nj} - \sum_{j=1}^{m} (t_j - t_n) q_{nj} - D(\mathrm{Q}) \quad (54)$$

As before, the equilibrium game has two stages and is solved in the reverse order. In the second stage, a country's firm chooses its output such that its profits are maximized taking as given the carbon tariffs of all countries.

Since countries are ex-ante symmetric, the profit function of a firm in any country belonging to the coalition, say 1, represents that of each of the other signatories. The profit of the firm in country 1 is expressed as,

$$\pi_1 = \sum_{j=1}^{n} \mathrm{P}_j \, q_{1j} - c q_1{}^s + t_1 q_1{}^s \quad (55)$$

Similarly, the profit of any firm in a non-signatory country, say n, represents that of firms in each of the other non-signatories. It is given as,

$$\pi_n = \sum_{j=1}^{n} \mathrm{P}_j \, q_{nj} - (c+t_n)\sum_{j=1}^{n} q_{nj} - \sum_{j=1}^{m} (t_j - t_n) q_{nj} \quad (56)$$

The term $\sum_{j=1}^{m} (t_j - t_n) q_{nj}$ represents the tax that a firm in a non-signatory country has to pay for its exports to all coalition countries.

To maximize the profit in (55), the first order conditions for the market in country 1 are obtained by differentiating π_1 by q_{11}, π_2 by q_{21} and so on up to π_n by q_{n1}. They are as follows,

$$\begin{aligned}
&\alpha - 2\beta q_{11} - \beta q_{21} - \ldots - \beta q_{n1} - c - t_1 = 0 \\
&\alpha - 2\beta q_{21} - \beta q_{11} - \ldots - \beta q_{n1} - c - t_2 = 0 \\
&\ldots \\
&\alpha - 2\beta q_{m1} - \beta q_{11} - \ldots - \beta q_{n1} - c - t_m = 0 \\
&\alpha - 2\beta q_{m+1,1} - \beta q_{11} - \ldots - \beta q_{n1} - c - t_{m+1} - t_1 + t_{m+1} = 0 \\
&\ldots \\
&\alpha - 2\beta q_{n1} - \beta q_{11} - \ldots - \beta q_{n-1,1} - c - t_n - t_1 + t_n = 0
\end{aligned} \quad (57)$$

Again, because the good is homogenous, the consumers do not care about the origin of the good. Therefore, I denote the supply of the good to country 1from all countries except 1 by $q_{i-1,\,1}$.

The first order conditions in (57), can be re-written as the following system,

$$
\begin{aligned}
&\alpha - 2\beta q_{11} - (n-1)\beta q_{i-1,1} - c - t_1 = 0 \\
&\alpha - \beta q_{11} - n\beta q_{i-1,1} - c - t_2 = 0 \\
&\ldots \\
&\alpha - \beta q_{11} - n\beta q_{i-1,1} - c - t_m = 0 \\
&\alpha - \beta q_{11} - n\beta q_{i-1,1} - c - t_1 = 0 \\
&\ldots \\
&\alpha - \beta q_{11} - n\beta q_{i-1,1} - c - t_1 = 0
\end{aligned}
\tag{58}
$$

The procedure similar to the one used for coalition structure C_1 to solve for the quantities of the good supplied to country 1 from all others is applied here. That is, denoting the supply of the good to country 1 from all countries except 2 by $q_{i-2,\,1}$ in (57) and so on for all n countries to obtain n systems of equations for market 1.

All n systems of equations are solved simultaneously for quantities supplied to 1 from all countries which are a function of tariff rates as given below,

$$
q_{11} = \frac{\alpha - c - mt_1 + \sum_{j\neq 1}^{m} t_j}{(n+1)\beta},\; q_{21} = \frac{\alpha - c - mt_1 + \sum_{j\neq 1}^{m} t_j}{(n+1)\beta},\; \ldots,\; q_{n1} = \frac{\alpha - c - mt_1 + \sum_{j\neq 1}^{m} t_j}{(n+1)\beta} \tag{59}
$$

This process of profit maximization can be repeated for markets in all signatory countries and the quantities so obtained can be generalized in the following expression. For any country i ϵ N and j ϵ L,

$$
q_{ij} = \frac{\alpha - c - mt_j + (t_1 + .. + t_{j-1} + t_{j+1} + .. + t_m)}{(n+1)\beta} \tag{60}
$$

To solve for profit maximization of a non-signatory, the first order conditions for the market in country, say n, are obtained by differentiating π_1 by q_{1n}, π_2 by q_{2n} and so on up to π_n by q_{nn}.

They are,

$$
\begin{aligned}
&\alpha - 2\beta q_{1n} - \beta q_{2n} - \ldots - \beta q_{nn} - c - t_1 = 0 \\
&\alpha - 2\beta q_{2n} - \beta q_{1n} - \ldots - \beta q_{nn} - c - t_2 = 0 \\
&\ldots \\
&\alpha - 2\beta q_{mn} - \beta q_{1n} - \ldots - \beta q_{nn} - c - t_m = 0 \\
&\alpha - 2\beta q_{m+1,n} - \beta q_{1n} - \ldots - \beta q_{nn} - c - t_{m+1} = 0 \\
&\ldots \\
&\alpha - 2\beta q_{nn} - \beta q_{1n} - \ldots - \beta q_{n-1,1} - c - t_n = 0
\end{aligned}
\tag{61}
$$

Let the supply of the good to country n from all countries except n by $q_{i-1,\ n}$. The above system of equations can then be reduced to the following set of equations,

$$
\begin{aligned}
&\alpha - 2\beta q_{nn} - (n-1)\beta q_{i-n,n} - c - t_n = 0 \\
&(n-1)\alpha - (n-1)\beta q_{nn} - n(n-1)\beta q_{i-n,n} - (n-1)c - \sum_{j=1}^{m} t_j - \sum_{\substack{j=m+1 \\ j\neq n}}^{n} t_j = 0
\end{aligned}
\tag{62}
$$

Denoting the supply of the good to country n from all countries except 2 by $q_{i-2,\ n}$ in (61) and so on for all n countries up to country (n-1) gives n sets of equations for the market in n.

The n sets are solved simultaneously to give the following relations,

$$
q_{1n} = \frac{\alpha - c - nt_1 + \sum_{j\neq 1}^{n} t_j}{(n+1)\beta},\ q_{2n} = \frac{\alpha - c - nt_2 + \sum_{j\neq 2}^{n} t_j}{(n+1)\beta},\ \ldots,\ q_{nn} = \frac{\alpha - c - nt_n + \sum_{j\neq n}^{n} t_j}{(n+1)\beta} \tag{63}
$$

This process repeated for all non-signatory countries gives a generalized expression for quantities such that for any country i ϵ N and j ϵ NL,

$$
q_{ij} = \frac{\alpha - c - nt_i + \sum_{j\neq i}^{n} t_j}{(n+1)\beta} \tag{64}
$$

The above expression is used to derive the total quantity of output and total quantity consumed by each country. For any country i ϵ N,

$$
q_i^{s} = \frac{\mathrm{n}\,\alpha - nc - n(n-m)t_i - \sum_{j=1}^{m} t_j + (n-m)\sum_{j\neq i}^{n} t_j}{(n+1)\beta} \tag{65}
$$

Again, output in any country is decreasing in domestic tariff and increasing in foreign carbon tariff. Further, the negative effect of domestic tariff on output is greater than the positive effect of foreign tariff.

Contrary to previous scenarios, the quantities consumed now depend on whether a country is a signatory or a non-signatory. They are given by the following,

$$q_i^{\ d} = \frac{\mathrm{n}(\alpha - c - mt_i + \sum_{j\neq i}^{m} t_j)}{(n+1)\beta} \ \forall i \in L \quad \text{and} \quad q_i^{\ d} = \frac{n\alpha - nc - \sum_{j=1}^{n} t_j}{(n+1)\beta} \ \forall i \in NL \tag{66}$$

The total quantity of the good, Q, available in the world economy is the sum of all output (or consumption) of the good given by,

$$Q = \frac{\mathrm{n}^2 \alpha - n^2 c - (2n-m)\sum_{j=1}^{m} t_j - (n-m)\sum_{j=m+1}^{n} t_j}{(n+1)\beta} \tag{67}$$

Having solved the second stage of the game, I will now solve the first stage where the signatories choose carbon tariffs such that the aggregate welfare of the coalition is maximized.

The aggregate coalition welfare with BTAs is given by,

$$\begin{aligned} W^{LB} = {} & \sum_{j=1}^{m} u_j(q_j^{\ d}) + (\sum_{j=1}^{n} P_j q_{1j} + \sum_{j=1}^{n} P_j q_{2j} + \ldots + \sum_{j=1}^{n} P_j q_{mj}) - c\sum_{j=1}^{n} q_j^{\ s} - \sum_{j=1}^{n} t_j q_j^{\ s} + \sum_{j=1}^{n} t_j q_j^{\ s} \\ & + \sum_{j=1}^{m} \sum_{i=m+1}^{n} (t_j - t_i) q_{ij} - mD(Q) \end{aligned} \tag{68}$$

The values of quantities from equations (65), (66) and (67) are inserted into (68) and the resultant expression is maximized with respect to all signatory tariff rates i.e. t_j for all j ϵ L.

The reaction function so obtained is given by,

$$\begin{aligned} & -(n^2 + 2m^2 - 3nm + m)\alpha + (n^2 + 2m^2 - 3nm + m)c - (m+1)(2nm^2 - n^2 m + n^2 + 2n - 2m)t_j \\ & -(n^2 + n^2 m - 2nm^2)\sum_{j=1}^{m} t_j - (3nm - m - 1)\sum_{j=m+1}^{n} t_j - (n^2 + 2m^2 - 6nm)\sum_{j=1}^{n} t_j \\ & + m(n+1)(2n-m)\gamma = 0 \end{aligned} \tag{69}$$

Further, each non-signatory maximizes its individual welfare. Inserting the quantities of output and consumption from equations (65), (66) and (67) into (54) and maximizing the resultant expression with respect to t_n gives the reaction function for n as,

$$(2nm-n^2)\alpha-(2nm-n^2)c-(n-m)(n+1)t_n-(n+1)\sum_{j=1}^{m}t_j-(n^2-nm-n+m-1)\sum_{j=1}^{n}t_j \quad (70)$$
$$+(n+1)\gamma=0$$

Imposing symmetry of carbon tariffs such that, $t_j = t_L$ for j ϵ L and $t_j = t_{NL}$ for j ϵ NL the reaction functions in (69) and (70) can be rewritten as the following expressions.

For signatories and non-signatories respectively,

$$-(n^2+2m^2-3nm+m)\alpha+(n^2+2m^2-3nm+m)c-(2n^2m+2m^3-4nm^2-2m^2$$
$$+n^2+2nm+2n-2m)\,t_L-(n-m)(n-m+1)(n-2m-1)t_{NL}+m(n+1)(2n-m)\gamma=0$$

and (71)

$$(2nm-n^2)\alpha-(2nm-n^2)c-m(n^2-nm+m)t_L-(n-m)(n^2-nm+m)t_{NL}$$
$$+(n+1)\gamma=0$$

Solving the welfare maximization conditions obtained for the coalition and the non-signatory in (71) gives the equilibrium tariff rates for the case of partial cooperation with BTAs.

The equilibrium tariff for the signatories in the presence of BTAs is[7],

$$t_L^{B*}=\frac{\begin{array}{c}-(\alpha-c)(2nm^3-3n^2m^2+n^3m+2m^3-6nm^2+3n^2m+m^2-2nm+n^2)\\+\gamma(n+1)(nm^3-3n^2m^2+2n^3m-m^3+2nm^2-2m^2+3nm-n^2+m+1)\end{array}}{(nm-n^2-m)(nm^2-n^2m+m^2-2nm-n^2+m-2n)} \quad (72)$$

[7] **The uniqueness of the equilibrium can be verified by,**

$$\frac{\partial^2 W_j^L}{\partial (t_L)^2}=\frac{-4m^3+8nm^2-4n^2m+4m^2-4nm-2n^2-4n-4m}{2(n+1)^2\beta}<0$$
$$\frac{\partial^2 W_j^{NL}}{\partial (t_{NL})^2}=\frac{-4m^3+8nm^2-4n^2m-2m^2+4nm-2n^2}{2(n+1)^2\beta}<0$$
$$\frac{\partial^2 W_j^L}{\partial t_L\partial t_{NL}}=\frac{4m^3-10nm^2+8n^2m-2n^3-2m^2+2nm-2m+2n}{2(n+1)^2\beta}$$
$$\frac{\partial^2 W_j^{NL}}{\partial t_{NL}\partial t_L}=\frac{4m^3-6nm^2+2n^2m-2nm-2m}{2(n+1)^2\beta}$$

The determinant of the Hessian is,

$\triangle^L<0$ and $\triangle^{NL}<0$

The equilibrium tariff for the non-signatories in the presence of BTAs is,

$$t_{NL}^{B*} = \frac{\begin{array}{l}(\alpha-c)(2nm^4-5n^2m^3+4n^3m^2-n^4m+2m^4-8nm^3+8n^2m^2-n^4\\+m^3-4nm^2+6n^2m-2n^3)-\gamma(n+1)(nm^4-3n^2m^3+2n^3m^2-m^4\\+2nm^3-2m^3+4nm^2-2n^2m+2m^2-2nm-n^2+2m-2n)\end{array}}{(n-m)(nm-n^2-m)(nm^2-n^2m+m^2-2nm-n^2+m-2n)} \tag{73}$$

From above, we see that the equilibrium tariffs of the signatories and the non-signatories depend on the parameters n, m, α, β, c and γ. The expressions can be manipulated such that they depend only on the parameters n, m, β and parameter ratio z where z = $\frac{\gamma}{(\alpha-c)}$ [8].

I assume in this model that a BTA must be strictly positive. That is, according to its definition, a BTA will exist only when the tariff of the signatories exceeds that of the non-signatories in equilibrium. In other words, for all parameter constellations where the non-signatory tax in t_{NL}^{B*} (73) exceeds the signatory tax t_L^{B*} in (72), a BTA will not be imposed by an IEA coalition on the non-signatories.

Therefore, to adhere to the non-negativity constraint of the BTA, all parameter combinations for which t_{NL}^{B*} exceeds t_L^{B*} are excluded from the comparative analyses between the BTA and non-BTA case.

Illustrated below is an example; given n = 10, Table 1 shows that for every coalition size m = 2, 3.., 9 there exists a threshold of the parameter z below which t_{NL}^{B*} exceeds t_L^{B*} in equilibrium i.e. the threshold below which a BTA will not be imposed by the coalition. I denote this threshold value of z as $\hat{z}$.

Number of countries n = 10

Coalition Size m	$\hat{z}$
2	–
3	–
4	0.00099
5	0.00612
6	0.01147
7	0.01823
8	0.02844
9	0.04762

Table 1

[8] The expressions are multiplied and divided by (α-c) or its multiples to obtain z. The impact of β is ignored since it serves only as a scaling parameter and does not affect the interactions between other parameters.

Equilibrium output and consumption of signatories and non-signatories obtained by inserting the equilibrium tariffs in (62) and (63) and are given by the following expressions.

Equilibrium output of a signatory i.e. for all $j \in L$ in the presence of BTAs is,

$$q_j^{sB*} = \frac{\begin{array}{c} n(\alpha - c)(nm^3 - 2n^2m^2 + n^3m + 2m^3 - 7nm^2 + 5n^2m + n^2) + \gamma(n^2m^4 - 4n^3m^3 + 5n^4m^2 - 2n^5m \\ -nm^4 + 2n^2m^3 + n^3m^2 - 2n^4m + n^2m^2 - 3n^3m + n^4 + m^3 - 3n^2m + 2n^3 + m^2 - 3nm + n^2 - n) \end{array}}{b(nm - n^2 - m)(nm^2 - n^2m + m^2 - 2nm - n^2 + m - 2n)} \tag{74}$$

Equilibrium output of a non-signatory i.e. for all $j \in NL$ in the presence of BTAs is,

$$q_j^{sB*} = \frac{\begin{array}{c} n(\alpha - c)(-2n^2m^2 + n^3m + 2m^3 + 2n^2m + n^3 + nm^3 + m^2 + 2n^2 - 6nm^2 - 3nm) + \gamma(n^2m^4 - 3n^3m^3 \\ +2n^4m^2 + 2n^2m^3 + 2n^2m^2 - n^3m - nm^4 + m^3 - 2n^2m - nm^3 + 2m^2 - n^2 + m - 2n - 3nm) \end{array}}{\mathrm{b}(\mathrm{n}\,m^2 - n^2m + m^2 - 2nm - n^2 + m - 2n)(nm - n^2 - m)} \tag{75}$$

Equilibrium quantity of consumption for the signatories i.e. for all $j \in L$ is given by,

$$q_j^{dB*} = \frac{\begin{array}{c} n(\alpha - c)(nm^3 - 2n^2m^2 + n^3m + m^3 - 3nm^2 + n^2m + n^3 + n^2) \\ -n\gamma(nm^3 - 3n^2m^2 + 2n^3m - m^3 + 2nm^2 - 2m^2 + 3nm - n^2 + m + 1) \end{array}}{\beta(nm^2 - n^2m + m^2 - 2nm - n^2 + m - 2n)(nm - n^2 - m)} \tag{76}$$

Equilibrium quantity of consumption for the non-signatories i.e. for all $j \in NL$ is given by,

$$q_j^{dB*} = \frac{n(n-m)(\alpha - c) - \gamma}{\beta(n^2 - nm + m)} \tag{77}$$

The equilibrium quantities of output and consumption obtained above are inserted into the expressions in (53) and (54) to obtain the representative equilibrium welfare of each signatory $\mathbf{W_j^{LB*}}$ and a non-signatory $\mathbf{W_j^{NLB*}}$ respectively in the presence of BTAs.[9]

As before, the welfare of a player in any group of countries, the coalition or the non-signatories, is negatively affected by its own tariff and positively affected by the tariff of the opposing group (see Footnote 5). Further, the negative impact of an increase in own tariff is larger than the positive impact of an increase in the opposing group's tariff.

[9] **The expressions for equilibrium welfares are very long. I refrain from printing them but they are available on request.**

7. Self –Enforcing IEAs: Participation and Stability

In the previous sections, the existence of an international environmental coalition has been pre-supposed and the focus has been on solving for the equilibrium and its dependence on coalition size for the non-BTA and BTA scenarios. To highlight the impact border tax adjustments have on participation in IEAs, I tackle the issue of coalitional stability below.

In reality, there exists no supranational authority to enforce environmental agreements. Therefore, for an IEA to exist, it must be self-enforcing. The idea of self-enforcement was first introduced in the cartel formation game by d'Aspremont et al. (1983, cited in Eyckmans & Finus, 2006a, b) along with the concepts of internal and external stability. Internal and external stability as defined by d'Aspremont are appropriate tools for assessing coalition stability in this paper as they embody the assumptions of open membership, single coalition and no consensus to accession.

An IEA is self-enforcing if no signatory has an incentive to leave the coalition (internal stability) and if no non-signatory has an incentive to join the coalition. Formally, an IEA with $m \in [1, \ldots, n]$ signatories is self-enforcing or stable if it satisfies the internal stability condition,

$$W_j^L(m) \geq W_j^{NL}(m-1) \tag{78}$$

and the external stability condition,

$$W_j^{NL}(m-1) \geq W_j^L(m) \tag{79}$$

In terms of welfare, this implies that an IEA is internally stable if the welfare of a signatory in a coalition of size m is equal to or greater than the welfare of a non-signatory with a coalition of size m-1. Similarly, an IEA is externally stable if the welfare of a non-signatory with a coalition of size m-1 is equal to or greater than the welfare of a signatory in a coalition of size m. Since the largest possible internally stable coalition must also be externally stable, the size of a stable IEA inherently depends on internal stability.

For given parameter constellations, the internal stability of any IEA is affected by the free-rider incentives that accompany environmental cooperation and the carbon tariff strategies of signatories and non-signatories.

Below, I analyze how IEA stability is driven by these factors, as well as how the imposition of a BTA changes strategic tariff interactions and free-riding incentives of the non-signatories.

7.1 Positive Externality Property of IEAs

Free-riding implies that a non-signatory to an IEA is better off by remaining an outsider and not participating (or participating less) in an environmental coalition while reaping the benefits of the coalition's mitigation efforts. Free rider incentives exist due to the positive externality that is conferred to non-signatories by an IEA coalition undertaking climate damage mitigation. This positive externality property (PEP) arises out of the pure public good nature of reduced environmental damages. Consequently, if the free rider incentive becomes stronger, that is, if the positive externality increases, one can expect cooperation and hence equilibrium coalition size of IEAs to decrease.

In quantitative terms, PEP is represented by the increase in welfare of non-signatories with respect to increase in coalition size (given n) i.e. PEP holds if $\frac{\partial W_j^{NL}}{\partial m} > 0$ for all $j \in NL$. Similarly, the Negative Externality Property (NEP) is said to hold if non-signatory welfare decreases as coalition size increases.

To determine the effect of parameter constellations on PEP the expressions for non-signatory welfare in both the non-BTA and BTA case are manipulated in Maple such that, given n, the resultant term depends on the parameter ratio z and coalition size m. Next, the relationship of the change in non-signatory welfare with coalition size i.e., $\frac{\partial W_j^{NL}}{\partial m}$, is analyzed for different parameter combinations. The following results are obtained,

- In the absence of BTAs, given n, PEP (NEP) is a consistently increasing (decreasing) function in z. Further, as m increases, PEP increases in all z, that is, the free-riding incentive gets larger as coalition size increases. Consequently, it is expected that internal stability decreases with the relative increase in damage parameter as well as with an increase in coalition size in the non-BTA scenario.

- In the presence of BTAs, given n, for small coalition sizes, PEP is an increasing function in z. However, as coalition size increases further, the negative externality property (NEP) effect increases for low values of z. For very large coalition sizes, PEP, and therefore the free-riding incentive, is a decreasing function over an increasingly larger range of z values. It can therefore be expected that, in general, internal stability increases as coalition size increases until the damage parameter becomes prohibitively relatively large.

- Comparison of the positive externality property between the BTA and non-BTA case shows that for large coalitions, the PEP effect of IEAs without BTAs is larger than that with BTAs. In other words, for larger coalitions, the free-riding incentive is smaller with BTAs than without. Therefore, there is a greater likelihood of larger coalitions being stable in the presence of BTAs than in their absence.

- For small coalition sizes in the BTA scenario, however, the opposite holds true. That is, for sufficiently small coalition sizes, the gain to non-signatories from the positive externality of an IEA outweighs the gain from becoming a signatory. This is an interesting result in that given some small coalition sizes, there is no BTA that can reduce the free-riding incentive of IEAs compared to the scenario without BTAs.

- In general, however, it is expected that internal stability for a given coalition size will be low in the absence of BTAs compared to the BTA case. Further larger coalitions exhibit a greater likelihood of being stable with BTAs than without.

7.2 Strategic Interaction of Tariffs

Internal stability of an IEA also depends on the strategic interaction between the emissions tariffs, that is, the domestic carbon tariffs imposed by the signatories and non-signatories on the production of the good.

For given parameter constellations, strategic complementarity of tariffs implies that both are an increasing function of coalition size i.e. $\frac{\partial t_L}{\partial m} > 0$ and $\frac{\partial t_{NL}}{\partial m} > 0$. In other words, all countries increase their mitigation efforts with increasing coalition size. Since a country is affected more negatively by an increase in own tariff than it is positively affected by an increase in the tariff of the opposition, when the tariffs are complementary, welfare of the signatories will increase and that of the non-signatories will fall. It is expected therefore, that strategic complementarity of tariffs will lead to an increase in internal stability of IEAs. Conversely, when the tariffs are strategic substitutes, i.e. $\frac{\partial t_L}{\partial m} > 0$ and $\frac{\partial t_{NL}}{\partial m} < 0$, the non-signatories counteract the increasing mitigation efforts of the coalition by reducing their own tariff. In this case, therefore, internal stability of IEAs is expected to fall.

As before, the expressions for equilibrium tariffs for the non-BTA and BTA cases are manipulated in Maple such that, given n, they depend on coalition size m and parameter ratio z. The following results are obtained,

- In the non-BTA scenario, given n, signatory tariff is an increasing function of coalition size i.e. $\frac{\partial t_L}{\partial m} > 0$ and non-signatory tariff is a decreasing function of coalition size $\frac{\partial t_{NL}}{\partial m} > 0$ for all values of $z \in [0, 1/\mathrm{n})$. In other words, the tariffs are always strategic substitutes.

- In the presence of BTAs, given n, signatory tariff is again an increasing function of coalition size, i.e. $\frac{\partial t_{NL}{}^{\mathrm{B}}}{\partial m} > 0$. Non-signatory tariff, on the other hand, is an increasing function in m initially for some low values of z below a threshold level beyond which it becomes a consistently decreasing function in coalition size i.e., $\frac{\partial t_{NL}{}^{\mathrm{B}}}{\partial m} < 0$. The tariffs of the signatories and non-signatories, therefore, exhibit complementarity for some low values of z beyond which they exhibit strategic substitutability.

Tables 2 and 3 show the strategic interaction between tariffs of the signatories and non-signatories for selected values of n and corresponding intervals of z in the non-BTA and BTA case respectively.

	Number of countries n						
	3	6	9	10	40	70	100
z interval	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation
0 - 1/5n	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes
1/5n - 2/5n	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes
2/5n - 3/5n	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes
3/5n - 4/5n	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes
4/5n - 1/n	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes

Table 2: Strategic Interaction of Tariffs without BTAs

	Number of countries n						
	3	6	9	10	40	70	100
z interval	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation	Tariffs' Relation
0 - 1/5n	Complements	Complements	Complements	Complements	Complements	Complements	Substitutes
1/5n - 2/5n	Complements	Complements	Complements	Complements	Substitutes	Substitutes	Substitutes
2/5n - 3/5n	Complements	Complements	Complements	Complements	Substitutes	Substitutes	Substitutes
3/5n - 4/5n	Complements	Complements	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes
4/5n - 1/n	Complements	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes	Substitutes

Table 3: Strategic Interaction of Tariffs with BTAs

From the above tables the following observations can be made,

- In the non-BTA case the tariffs of the signatories and non-signatories consistently exhibit strategic substitutability as the parameter z increases for any n. Therefore, it is expected in the non-BTA scenario internal stability remain low and/or decrease as z increases i.e. as the damage parameter becomes relatively larger.

- In the BTA case, when the number of countries n is low, the tariffs exhibit strategic complementarity over all z. As n increases, the threshold of z below which the tariffs remain complementary decreases up to the point where the tariffs exhibit complementarity only for low values of z and as z becomes relatively larger, the tariffs change from being complements to substitutes For sufficiently large n, signatory and non-signatory tariffs are strategic substitutes over all z.

- Finally, given n, the comparison of tariff interaction in the two scenarios shows that, the tariffs are strategic complements over a larger range of parameter combinations in the BTA case compared to the non-BTA case. That is, for a given combination of parameters, in general, internal stability with BTAs is expected to be higher than that without BTAs.

7.3 Internal Stability Analysis

For the purposes of this research, the impact of BTAs on coalition stability and participation is represented by comparing average maximum coalition size and absolute maximum coalition size in equilibrium in the non-BTA case with those in the presence of BTAs.

Equilibrium coalition size is determined using the internal stability analysis. The analysis is conducted using Maple with the equilibrium welfares obtained for signatories and non-signatories in the non-BTA and BTA case. First, the general expressions for all m and n representing internal stability as given in (78) are calculated for the BTA and non-BTA scenarios. Next, these expressions are evaluated at different values of n and, as described before, manipulated such that their value depends only on the ratio z and coalition size m. For a coalition of any size to be internally stable the sign of the expressions must be positive.

For each n there exists a coalition size beyond which the IEA is not internally stable, that is, the largest internally stable coalition, which depends on the specific value of the ratio z. Since the largest internally stable coalition must also be externally stable, I denote the largest overall stable coalition by $\max m^{**}$.

Table 4 and Table 5 show how internal stability and, hence, $\max m^{**}$ changes with the number of countries n and the corresponding intervals of z for non-BTA and BTAs scenario respectively. Also shown are the average largest stable coalitions calculated for any given n denoted by Avg $\max m^{**}$ which represent the average success rate of an IEA.

	Number of Countries n						
	3	6	9	10	40	70	100
z interval	max m**	max m**	max m**	max m**	max m**	max m**	max m**
0 - 1/5n	3	1	5	5	20	35	50
1/5n - 2/5n	3	3	5	5	19	33	47
2/5n - 3/5n	3	3	4	5	18	31	43
3/5n - 4/5n	3	3	4	5	17	29	41
4/5n - 1/n	3	3	4	4	16	27	38
Avg max m**	3	2.6	4.4	4.8	18	31	43.8
Avg Success Rate	100%	43%	48.88%	48%	45%	44.28%	43.80%

Table 4: Coalition Stability without BTAs

Number of Countries n

z interval	3	6	9	10	40	70	100
	max m^{**B}	max m^{**B}	max m^{**B}	max m^{**B}	max m^{**B}	max m^{**B}	max m^{**B}
0 - 1/5n	1	4	6	7	36	66	95
1/5n - 2/5n	2	5	8	8	37	66	90
2/5n - 3/5n	2	5	8	9	31	51	72
3/5n - 4/5n	2	5	8	9	26	43	61
4/5n - 1/n	3	5	7	7	23	38	53
Avg max m^{**B} w/ BTA	2	4.8	7.4	8	30.6	52.8	74.2
Avg Success Rate w/ BTA	67%	80%	82.22%	80%	76.50%	75.43%	74.20%

Table 5: Coalition Stability with BTAs

From the above two tables, the following observations can be made about internal stability and success of IEAs,

- The grand coalition is not stable for any n >3.
- For low n, $\max m^{**}$ increases as z increases in the non-BTA scenario. However, as n becomes larger, $\max m^{**}$ decreases consistently for increasing values of z.
  In the BTA case for low n, $\max m^{**B}$ increases as z increases. As n becomes larger, $\max m^{**B}$ changes from an increasing to a decreasing function in z to the point where for sufficiently large n, $\max m^{**B}$ is a consistently decreasing function in z.
- To generalize, except for small values of n, largest internally stable coalition size is a decreasing function in z. That is, as the damage parameter γ becomes relatively larger, internal stability falls.
- Comparisons between the two scenarios show that for any n > 3 and a given interval of z, the size of the largest internally stable coalition for the BTA case is larger than that in the non-BTA case. Further, the average largest stable coalition size, Avg $\max m^{**}$ and therefore average success rate is greater in the presence of BTAs than in the absence for all n > 3.
- The average success rate of an IEA initially increases for low n. However, beyond some threshold value of n, the average success rate of IEAs decreases consistently as n increases. Another observation from the analysis (not shown), is that the values of z i.e. the number of combinations of parameters α, c and γ for which internal stability holds also decrease significantly as n increases. This result echoes Barrett's (1994) 'paradox' of cooperation, that is, whenever the degree of negative externality becomes larger, IEAs achieve lesser in terms of participation. It can be concluded, therefore, that BTAs can indeed improve upon participation and stability in IEAs.

Another approach to depicting the impact of a BTA on coalition size uses the more generalized observations of absolute maximum coalition size and, hence, the absolute limit of success of participation in IEAs. Table 6 and 7 below illustrate the findings of the absolute largest stable coalition size $\max m^{**}$ and the corresponding success rate of IEAs for the non-BTA and the BTA case respectively. I use an extended set of n values for a more detailed analysis of robustness of results.

	Number of Countries (n)																
	3	4	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100
$\max m^{**}$	3	2	3	3	4	4	5	5	10	15	20	25	30	35	40	45	50
Success Rate (%)	100	50	60	50	57.14	50	55.55	50	50	50	50	50	50	50	50	50	50

Table 6: Largest Stable Coalitions without BTAs

	Number of Countries (n)																
	3	4	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100
$\max m^{**}$ with BTA	3	3	4	5	6	7	8	9	18	28	37	47	56	66	76	86	95
Success Rate (%)	100	75	80	83.33	85.71	87.5	88.88	90	90	93.33	92.5	94	93.33	94.28	95	95.55	95

Table 7: Largest Stable Coalitions with BTAs

As before, the absolute maximum stable coalition size and, hence, maximum possible participation given any n is larger in the BTA case than that in the non-BTA case.

From the above stability analyses, I can conclude therefore, that even though the relative increase in the damage parameter and increase in n both negatively affect cooperation in IEAs, BTAs are effective as a means of increasing coalitional stability and participation in when they imposed by coalition countries on the imports from the non-signatory countries. These results fulfill the expectations derived from the PEP and strategic tariff interaction analyses in the previous section.

8. Credibility and Environmental Effectiveness of Border Measures

Below I address the issue of the impact of the imposition of border tax adjustments on welfare and emissions. That is, I determine whether BTAs are credible as a policy option compared to free trade in terms of damage mitigation efforts, welfare of the players involved and the welfare of the world as a whole.

This is done by comparing the equilibrium values of output and welfare in the non-BTA scenario with those in the BTA scenario. All comparisons employ the use of statistical averages of the variable using the results obtained from the internal stability analyses where for a given parameter constellation, there exists a largest possible stable coalition size, denoted by $\max m^{**}$ and $\max m^{**B}$ in each scenario. For the comparison of average values of variables, given n, the total quantity of any variable being compared is calculated at each value of $\max m^{**}$ in the different z intervals and then averaged. The procedure is repeated for each n, for each variable to be compared and for both non-BTA and BTA scenarios.

As mentioned before, for each combination of n and m in the BTA scenario, there exists a threshold $\hat{z}$ below which the BTA does not exist. For each n, therefore, the values of the threshold $\hat{z}$ corresponding to each $\max m^{**B}$ are used to obtain an average of the z values below which a BTA is not imposed. Denoted by Avg $\hat{z}$, this average threshold is employed during the comparative analyses of variables. Table 8 below, shows these Avg $\hat{z}$ for each n used in the analyses.

Number of Countries n	Avg $\hat{z}$*
3	0.14286
4	0.09613
5	0.08111
6	0.06953
7	0.05720
8	0.04596
9	0.04158
10	0.03203
20	0.01002
30	0.00412
40	0.00283
50	0.00214
60	0.00154
70	0.00128
80	0.00111
90	0.00097
100	0.00057

Table 8

* Approximated

This threshold value decreases as the number of countries increases. That is as n increases, a consistently lesser amount of environmental damage is sufficient for the global economy as a whole to benefit from the imposition of a BTA.
In other words, for a sufficiently large number of countries, the imposition of a BTA, so that it is profitable for the world as a whole, is justified even when the environmental damage is low.

8.1 Output

Environmental damage from GHG pollution is trans-boundary in nature. That is, carbon emissions from production of a good impact all countries of the world equally, regardless of the place of origin of those emissions. Therefore, when determining the impact of any policy measure purposed to reduce emissions, the metric which carries the most relevance is one measuring the change in emissions on a global scale.
In this paper, environmental damage from emissions is directly proportional to global output of the good. Consequently, to study the environmental effectiveness of a border measure, I compare average total world output in the presence of the BTA with that in the absence of the BTA.

Further, border carbon adjustments have been opposed on the basis of them being a 'murky trade barrier' (Helm et al., 2012) in that they have a contractionary effect on output. It is, therefore, worthwhile to determine how the output of a signatory or a non-signatory responds to the imposition of a BTA. Note, however, that the potential of a border measure to potentially contract production and thereby reduce international trade does not mean that BTAs create a distortion; it is, in fact, the incorrect pricing of carbon that leads to overproduction and overconsumption of carbon-heavy goods.

8.1.1 Average Signatory Output

To determine the impact of a BTA on the output of any signatory, average signatory output without BTAs is subtracted from average signatory output with BTAs. The resultant term is normalized and then manipulated such that it depends only on the parameter ratio z. The process is repeated for each n and the following observations are made,

- For n = 3, average signatory output with BTA exceeds that without BTA for all permissible values of z (z > Avg $\hat{z}$). This unexpected result is reasoned using the internal stability analysis wherein the grand coalition is the only stable outcome for n = 3 in the case without BTAs. On the other hand, with BTAs, the partial cooperation coalition structure of m = 2 is also stable for certain parameter combinations (see Table 5). Since the grand coalition is the social optimum where all negative externalities are internalized completely, signatory output in the grand coalition will be the lowest of that of the signatories in any other partial cooperation scenario. For this reason, for n =3, the average signatory output without BTAs is lower than that in the non-BTA case.

- For all n > 3, average signatory output with BTAs is lower than that without BTAs for all permissible z values.

8.1.2 Average Non-Signatory Output

Average non-signatory output without BTAs is subtracted from average non-signatory output without BTAs and the resultant term is manipulated such that it depends only on the parameter ratio z. It is found that for all n, non-signatories on average produce less output in the presence of BTAs compared to their average output in the absence of BTAs for all permissible z values.

8.1.3 Average Total World Output

Average total world output without BTAs is subtracted from average total world output with BTAs for each n in the analysis. The resultant term is manipulated such that it depends only on the parameter ratio z. Repeating this process for all values of n, the following observations are made,

- For n = 3, average total world output with BTA exceeds that without BTA for some values of z.
  Again, this result can be explained by the fact the grand coalition is the only stable outcome without BTAs while a BTA increases coalitional stability such that partial cooperation with m = 2 is also stable. Since the grand coalition is the social optimum, total world output is also the lowest compared to that in any other partial cooperation scenario. For this reason, average world output for n = 3 without BTAs is lower than that in the non-BTA case for some parameter constellations.

- For all n > 3, average total world output with BTAs is lower than that without BTAs for all permissible z values.

In general, it can be concluded that signatories as well as the non-signatories produce less output after BTAs are imposed compared to the no BTA scenario. Due to this, average total world output of the good and hence average environmental damage from emissions during production is also lower in the presence of BTAs compared to that in the absence of BTAs. This result holds true for all values of n and the corresponding parameter constellations except for the case of n = 3 where average signatory output and hence average total world output with BTAs actually exceeds that in the non-BTA case for some parameter combinations. Treating this case as an exception, the generalization is that average total production of the good and hence the damages from emissions fall when BTAs are introduced.

8.2 Welfare

As mentioned before, the threat of a border carbon adjustment is considered credible only if the welfare of the imposing party, i.e. the signatories to the IEA in this model, increases after the adjustment. Credibility is ascertained by comparing average signatory welfare in the presence of the BTA with that in its absence. It is also important to determine the impact of the adjustment on the welfare of the non-signatories as this answers the question of whether a BTA can be pareto-improving for all players involved. The potential of a BTA to increase the welfare of non-signatories provides an incentive for them to adjust their carbon pricing policy in line with the signatories and thus move towards a cooperative outcome

The notion of 'credibility' of a BTA with respect to signatory welfare is, however, shortsighted. As discussed previously, from a political and social standpoint, the underlying motive of imposing trade restrictions like border carbon adjustments should be to mitigate environmental damage. It may be the case that a border adjustment is not 'credible' in that it does not increase signatory welfare compared to the no BTA case. However, the detrimental effects of GHG emissions and climate change are of a global nature. True credibility of a border adjustment must, therefore, be debated based on its impact on total global welfare. That is, assessing the core advantage or disadvantage of BTAs involves determining whether the world as a whole benefits from border adjustments even if some players may not.

8.2.1 Average Signatory Welfare

Average signatory welfare without BTAs is subtracted from average signatory welfare with BTA. The resultant term is manipulated such that it only depends on the parameter ratio z. The process is repeated for each n to obtain the following observations,

- For $n = 3$, average signatory welfare with BTAs is less than that without BTAs for all permissible z values.
  Once again, this result may be explained using the fact that the grand coalition is the only stable coalition size without BTAs whereas in the presence of BTAs, partial cooperation is also a stable outcome for $n = 3$. Since the grand coalition is the social optimum it internalizes the negative externality of environmental damage fully. Signatory welfare in the grand coalition is, therefore, the highest of that of the signatories in any other partial cooperation structure. For this reason, average signatory welfare without BTAs will also be higher than that with BTAs for all possible parameter combinations.

- For all $n > 3$, average signatory welfare with BTAs exceeds that without BTAs for all permissible z values.

BTAs serve as an additional policy option for an IEA to exercise greater control over the production of a good and therefore the amount of environmental damage via tariff interaction. From previous sections, it is observed that the imposition of a BTA leads to larger stable coalitions while simultaneously reducing the average output of a signatory ($n > 3$). Therefore, the effect on signatory welfare with BTAs can be attributed to the relative impact of decreasing firm profits due to reduced output, larger tariff revenue and decreasing environmental damage. It becomes obvious then that the positive impact of decreasing damages and increasing tariff revenue offsets the decrease in firm profits which leads to an increase in signatory welfare in the presence of BTAs. This reasoning is backed by the fact that this result holds for *all* coalition sizes, given n, and not just on average. That is, the welfare of a signatory with BTAs is greater than that without BTAs, given n, for all possible coalition sizes (and the corresponding permissible z values).

8.2.2 Average Non-Signatory Welfare

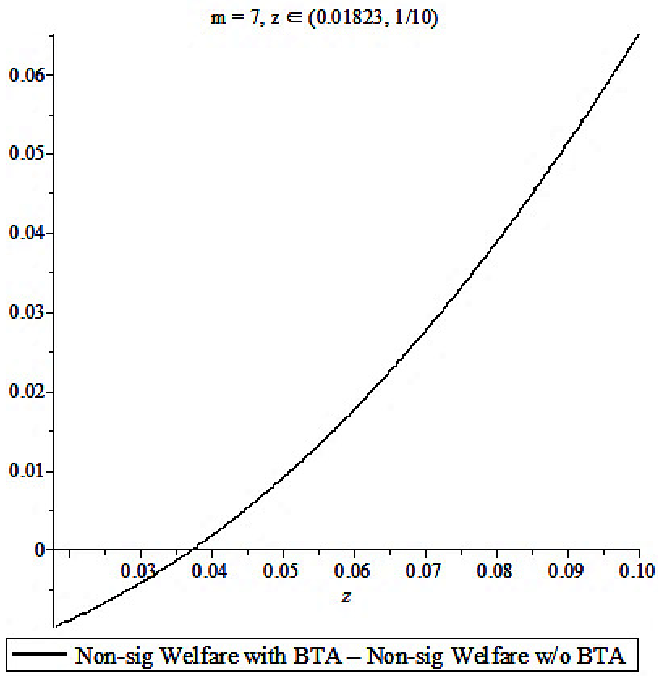
Average non-signatory welfare without BTAs is subtracted from average non-signatory welfare with BTAs and the resultant term is manipulated such that it depends only on the parameter ratio z.

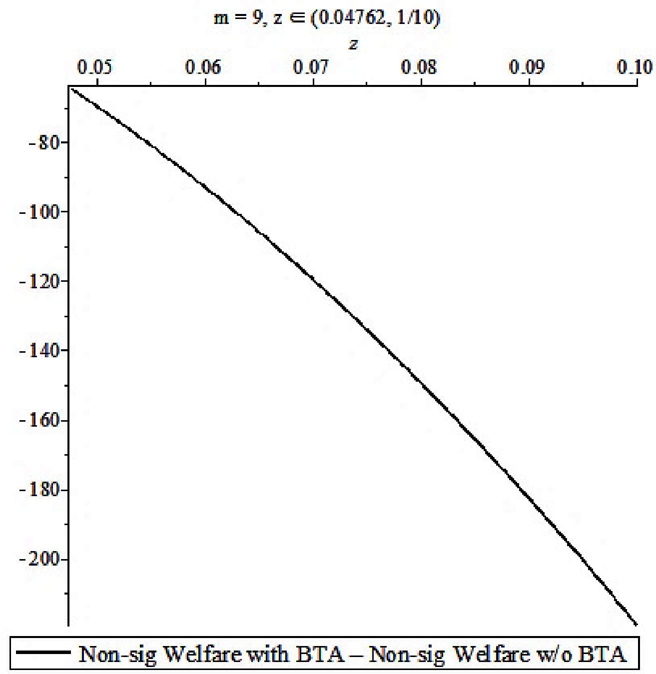
After repeating the process for all n, it is found that average non-signatory welfare with BTAs exceeds that without BTAs for all n and all permissible z values corresponding to each n. This may be attributed to the increase in the positive externality conferred by the larger IEAs that exist with BTAs by way of reduced environmental damages.

However, from the observations on non-signatory output, it can be concluded that the fall in output will decrease the profits of the firm in the non-signatory country. This fall in firm profit is compounded by the existence of the BTA which serves as an additional tariff that the firm in the non-signatory countries must pay to export to coalition countries. The combined effect of reduced output and increased tariff payments will, therefore, reduce non-signatory welfare.

Consequently, it is worthwhile to investigate whether the average result above is backed by specific comparative results i.e. whether a non-signatory is always better off in the presence of a BTA than in its absence. This inquiry departs from the analysis of the average as it investigates the impact of a BTA on non-signatory welfare for *all* possible coalition sizes, given n.

I take the example of $n = 10$ and illustrate below, with the help of graphs, the difference between non-signatory welfare with and without BTAs for coalition sizes $m = 7, 9$.





The panel on the left graphs the difference between average non-signatory welfare with BTA and average non-signatory welfare without BTA for m = 7. The permissible values of z for which a BTA holds for this combination of n and m lie between (0.018233, 1/10).

Contrary to the average non-signatory welfare comparative analysis result, at n = 10 and m = 7, the welfare of a non-signatory with BTAs is less than that without BTA for some low values of z. That is, when the damage parameter is relatively small, the gain in welfare from reduced environmental damages does not offset the loss in firm profits from reduced output and the BTA tariff. [10]

Similarly, the panel on the right shows that for m = 9, non-signatory welfare with BTAs is less than that without BTAs for all permissible z values (0.04762, 1/10). That is, when the coalition is large enough, no amount of welfare gain from reduced damages offsets the welfare loss from reduced profits and BTA tariff payments.

This is an interesting result because while the 'credibility' aspect of the BTA is upheld in that it is welfare-improving for the signatories in all possible cases, the same does not hold for non-signatories. That is, for some combinations of n and m, non-signatories may be worse off with the BTA than without, implying that a BTA may not always be pareto-improving in terms of welfare for all players involved.

[10] For n = 10 and m = 7, the output of a non-signatory with BTAs is less than that without BTAs for all permissible values of z.

8.2.3 Average Total World Welfare

The analysis is conducted in Maple where average total world output without BTAs is subtracted from that with BTAs for a given n and the resultant expression manipulated such that it depends only on the parameter ratio z. The process is repeated for each for the respective permissible z values and the following observations are made,

- For $n = 3$, average total world welfare without BTAs is greater than that in the presence of BTAs for all corresponding parameter combinations.
  Again, this result can be explained by the fact that, without BTAs, the only stable coalition for $n = 3$ is the grand coalition, whereas when BTAs are imposed, partial cooperation is also a stable outcome. Since the grand coalition is the social optimum, the global welfare with a grand coalition structure is the highest of all other partial cooperation coalition structures, irrespective of whether BTAs are imposed or not. For this reason, the average of total world welfare for $n = 3$ is always higher without BTAs than when BTAs are imposed.

- For $n > 3$, average total world welfare with BTAs exceeds that without BTAs above a threshold value of z. That is, the world as a whole benefits from the imposition of a BTA compared to the no BTA case. This global increase in welfare can be attributed to larger coalition sizes after the BTA is imposed which internalize a larger amount of the pollution externality combined with the gains from decreasing environmental damage due to reduced global output.

9. Conclusion

This paper contributes to the discussion of using trade sanctions as an instrument to affect cooperation in international climate agreements by investigating the impact of a border carbon adjustment on stability and participation in an IEA. Against the background of coalition formation, I present a simple trade model that incorporates climate policy to study equilibrium participation strategies of players in partial cooperation with and without a BTA. My model is a modification of Eyland and Zaccour's (2012) two-country model on strategic decisions of firms on carbon tariffs and outputs in the presence of a BTA and the welfare implications of the same. The drawback to their model is that it abstracts from the real world by disregarding multilateral trade. My paper corrects for this drawback by introducing an n-country setup which is conducive to the study of coalition structures.

In this model the signatories to an IEA impose a BTA on the imports from non-signatories adjusting for the full domestic carbon tariff differential between the coalition and the non-members. The concept of internal and external stability, as defined by d'Aspremont, is employed to determine the impact of this border adjustment on equilibrium coalition size and participation rate in the IEA. To answer the central question of the paper, comparative results for the non-BTA and BTA scenario are summarized as follows,

- Given specific parameter combinations, the prospects of a given coalition size being stable are higher in the presence of the BTA that without.
- The largest coalition size that is stable with BTAs is larger than that without BTAs for all parameter combinations. This result also holds on average for all values of n except n = 3 which is treated as an exception.
- Given n and for all possible parameter combinations, the average participation rate in IEAs is unambiguously higher in the presence of BTAs compared to the non-BTA scenario. This conclusion also holds for the absolute largest participation rate possible in the IEA.

The paper goes on to analyze the implications of the border adjustment for global welfare and output. This is done to justify its imposition as a credible and effective measure to attain the underlying objective of reducing global GHG emissions and in the process increasing welfare. The following results are obtained,

- Signatories as well as non-signatories on average produce less output and hence generate lower emissions in the presence of BTAs compared to the non-BTA case.
- Average total world output with the BTA is also lower compared to the non-BTA scenario for all permissible parameter combinations. I conclude in the paper, therefore, that the imposition of a border adjustment can reduce the amount of global GHG emissions thereby achieving its goal of environmental effectiveness.

- On average the signatories as well as the non-signatories receive larger welfare with the BTA than without.

- The BTA is beneficial for the world as a whole in that the average total world welfare with BTAs is higher than that without for all permissible parameter combinations. This serves as an analytical follow-up to conclusions from theoretical studies like Gros and Egenhofer (2011) that a border adjustment can improve global welfare.

While, this paper captures the basic idea of using trade restrictions like border measures to encourage and enforce participation in IEAs, the model developed is limited in scope in that it does not model the various complexities of international trade and climate agreements. For example, the assumptions of ex-ante symmetric countries as well as a homogeneous good constrain the real world applicability of the qualitative results. Extensions to this model may include the reality of heterogeneous regions in terms of asymmetries in cost and incentive structures as well as product differentiation whereby goods from different regions are imperfect substitutes.

Further, the border tariff adjustment modeled in this paper assumes full adjustability of the difference in carbon prices. In practice, however, this is an extreme case and may not be considered legally or politically acceptable under the UNFCCC or WTO rules. Moreover, my model limits the availability of a border measure only to signatories to the IEA whereas a unilateral border measure may well trigger a strategic reply by affected region (Helm et al., 2012). Incorporating different national responses to border measures in trade models would, therefore, mimic more effectively the reality of the strategic economic and political interactions between world regions. The effectiveness of other iterations of border measures, such as export rebates or output-based allocation has also been compared in terms of leakage and firm competitiveness (see Fischer and Fox, 2012; Monjon and Quirion, 2011) but they may also be studied for their impact on formation and participation in self-enforcing IEAs.

The restrictive assumptions of my model serve the purpose of tractability but are in line with the relevant literature on the topic that also circumvents analytical complexities by resorting to simple functional forms. Further research on the supportive role border carbon adjustments can play in climate policy, with weaker assumptions and extensions to the design of border adjustments (see Section 3), will move forward the debate on how to mitigate climate change.

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